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Reassessment of the potential radiological doses for residents resettling Enewetak Atoll

W. L. Robison

W. A. Phillips

M. E. Mount

B. R. Clegg

C. L. Conrado

October 30, 1980

Lawrence Livermore National Laboratory

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LAWRENCE LIVERMORE LABORATORY
University of California • Livermore, California • 94550

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GLOSSARY OF ACRONYMS

BNL	Brookhaven National Laboratory
DOE	Department of Energy
DRI	Desert Research Institute
EF	Enhancement factor
EML	Environmental Measurement Laboratory
FPD	Finite probability distribution
FPDB	Fission Product Data Base
HPGe	high purity germanium
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IMD	Individual Medical and Diet Survey
IMSL	International Mathematics and Statistical Laboratory
LLNL	Lawrence Livermore National Laboratory
MDA	Minimum detectable activity
MLS	Micronesian Legal Service
NCRP	National Council on Radiation Protection
NVOO	Department of Energy Nevada Operations Office
PACE	Pacific Area Cratering Experiment
PDE	Personal dosimeter enhancement
TLD	Thermoluminescent dosimeter
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USAEC	United States Atomic Energy Commission

REASSESSMENT OF THE POTENTIAL RADIOLOGICAL DOSES FOR RESIDENTS RESETTLING ENEWETAK ATOLL

EXECUTIVE SUMMARY

The purpose of this report is to refine the dose predictions, subsequent to the cleanup effort, for alternate living patterns proposed for resettlement of Enewetak Atoll.

The most recent data developed from projects at Enewetak and Bikini Atolls for concentration and uptake of Cs, Sr, Pu, and Am were used in conjunction with recent dietary information and current dose models to predict annual dose rates and 30- and 50-y integral doses (dose commitments).

The terrestrial food chain is the most significant exposure pathway—it contributes more than 50% of the total dose—and external gamma exposure is the second most significant pathway. Other pathways evaluated are the marine food chain, drinking water, and inhalation.

Cesium-137 produces more than 65% of the predicted dose; ^{90}Sr is the second most significant radionuclide; ^{60}Co contributes to the external gamma exposure in varying degrees, but is a small part of the total predicted dose; the transuranic radionuclides contribute a small portion of the total predicted lung and bone doses but do present a long-term source of exposure.

Maximum annual dose rates predicted for Enjebi (Janet) Island in the northern end of Enewetak Atoll are 291 mrem/y for bone marrow and 277 mrem/y for whole body when imported foods are available. When imported foods are unavailable the bone-marrow and whole-body maximum annual doses are predicted to be 554 mrem/y and 509 mrem/y, respectively. The 30-y integral doses for Enjebi (Janet) Island are estimated to be 5.7 rem (whole body) and 6.1 rem (bone marrow) when imported foods are available and 10 rem and 11 rem, respectively, when imported foods are unavailable.

For the southern half of Enewetak Atoll the maximum annual dose rates when imported foods are available are estimated to be 4.5 mrem/y (whole body) and 5.1 mrem/y (bone marrow); when imported foods are unavailable the dose rates are 8.6 mrem/y (whole body) and 11 mrem/y (bone marrow). The 30-y integral doses are 0.10 rem (whole body) and 0.12 rem (bone marrow) when imported foods are available and 0.20 and 0.26 when imported foods are unavailable.

Nearly all of the parameters in the dose models have log-normal distributions. Two different methods for developing the distribution in the final estimated doses, based upon the distribution of each of the model parameters, indicate that the distribution of

estimated doses is also log-normal. The doses listed above (and in the rest of the paper) are calculated with the average value for each of the model parameters and, as a result, fall at about the 65th percentile on the dose-distribution curve.

The appendices mentioned in this report are available from the authors on request.

INTRODUCTION

BACKGROUND AND PURPOSE

The Enewetak people were relocated to Ujelang Atoll in 1948 so that the United States could conduct part of its nuclear testing program at Enewetak Atoll. In 1972, at the request of the Enewetak Council, the U.S. Government began the process of returning Enewetak Atoll to the Enewetak people. A part of the U.S. Government's responsibility was to determine the radiological status of the atoll and to estimate the radiological doses as a consequence of resettlement. Therefore, a preliminary survey was conducted from October 1972 through February 7, 1973. The results of this survey and the associated assessment were published in late 1973.[1]

The general conclusions from that survey were:

1. The terrestrial food chain is the greatest source of potential dose to a returning population.

2. Cesium-137 and ^{90}Sr will be the most significant radionuclides over the next few decades.

3. Living patterns involving the northern half of the atoll will result in radiation exposure that would exceed U.S. Federal Guidelines—the southern half of the atoll presents no problem for either residence or agriculture.

4. The transuranic isotopes are a long-term source of exposure in the northern and eastern regions of the atoll.

Since the initial radiological survey, more data have been accumulated concerning the concentration and uptake of the radionuclides in terrestrial and marine food chains. In addition, new data were obtained for external gamma exposures and soil radionuclide concentrations following a large cleanup effort begun in 1978; this cleanup was directed toward removing scrap and debris over the entire atoll and removing soil from areas with the highest concentrations of transuranics in the soil.

The purpose of this report is to refine the dose predictions, subsequent to the cleanup effort, for alternate living patterns proposed for resettlement of Enewetak Atoll.

We predict doses for what we feel are the most probable living patterns; data necessary for developing other dose predictions can be found in the Appendices, which are available on request from the authors.

LIMITATIONS OF THE ASSESSMENT

The programs to develop better data on concentration and uptake of radionuclides in subsistence foods were begun on Enewetak Atoll in August 1975 and on Bikini Atoll in August 1977 by planting test plots of coconut, breadfruit, *Pandanus* sp., papaya, banana, squash, sweet potato, and watermelon. The Trust Territory had sponsored a large-scale coconut planting program on Bikini and Eneu Islands at Bikini Atoll in 1970-1971; some breadfruit and *Pandanus* sp. were also planted. Samples of annual crops (papaya, banana, squash, watermelon, and sweet potato) have been collected in the first 1.5 years after each test plot was established. The more important subsistence foods such as coconut, breadfruit, and *Pandanus* sp. are essentially unavailable at Enewetak and will not be available from our test plots for perhaps another year. Coconut, breadfruit, and *Pandanus* trees planted at Bikini Atoll in 1970 have begun bearing fruit only in the past two years. Uptake and concentration ratio (plant/soil) data are developed from these subsistence crops whenever samples are available. However, the data base for each subsistence crop is not as large or complete as it will be in two or three more years.

Because subsistence foods are essentially unavailable in the northern part of Enewetak Atoll, the assessment has been made using data on concentration ratios developed primarily at Bikini Atoll and applied to Enewetak Atoll. It would be preferable to be able to base the predictive assessment on a larger data bank of concentration ratios for each subsistence food. We will of course update the estimated doses for living patterns at Enewetak Atoll as more data are collected and as food crops become available for direct analysis.

The marine environment and the groundwater have been studied at Enewetak and Bikini since 1974 and these studies have supplied more complete data for evaluating those pathways. More data are needed to evaluate the radionuclide concentrations in cistern water.

More recently, rather detailed experiments have been conducted at Bikini Atoll to determine the rate and source of resuspended aerosols and to provide the data needed to evaluate the inhalation pathway. These results have been applied to Enewetak Atoll and initial experiments at Enewetak do confirm the Bikini data.

Starting in February 1979 after much of the cleanup was completed, soil samples were collected on a 50-m grid on all of the northern islands at Enewetak Atoll to determine the concentration of ^{137}Cs and ^{90}Sr in the soil; because of time and budget restrictions, only samples on a 100-m grid were analyzed for ^{90}Sr; all samples were analyzed for ^{137}Cs. In addition external gamma-exposure rates were measured on a 25-m or 50-m grid on all islands.

The Department of Energy Nevada Operations Office (NVOO) was responsible for the soil-sampling project with technical assistance from LLNL. The NVOO was also responsible for analyzing the soil samples and for the quality control program; the radionuclide concentration data, referred to as the Fission Product Data Base (FPDB), were used by LLNL as the basis for the radiological dose assessment. In addition the NVOO was responsible for developing the external gamma-exposure rates which LLNL subsequently used for evaluating the potential external exposure dose for a returning population; EG&G made the external gamma field measurements under contract to DOE NVOO.[2]

The FPDB forms the basis for evaluating the terrestrial food chain. We would prefer that the entire potential data base were available, but as a result of the mentioned constraints we are basing the ^{90}Sr assessment on the 100-m grid data. We are evaluating the distribution and ranges of the soil radionuclide concentration for each island to determine whether analysis of the other samples will be necessary.

In addition, external gamma and soil data are only recently available for the islands in the northwest quadrant of the atoll, i.e., Bokoluo (Alice), Bokambako (Belle), Kirunu (Clara), Louj (Daisy), Bokinwotme (Edna), and for Boken (Irene) and Runit (Yvonne) Islands on the eastern side of the atoll (Fig. 1). The data may be evaluated and assessed later. However, these islands are not included as residence or agriculture islands in any of the resettlement options described in the rehabilitation plans.

Limited data are available for the ^{241}Pu concentration in soil on the islands. For Enjebi (Janet) we have used the ^{241}Pu soil data from our test plot on Enjebi (Janet) Island to determine the "grow-in" of ^{241}Am, the daughter product of ^{241}Pu; the $^{241}Pu/^{241}Am$ ratio observed in Enjebi (Janet) was then applied to other islands at the atoll.

A very critical aspect of the dose assessment is the assumed average dietary intake of all foods for the returning population. The estimated doses will scale directly with the picocurie per day (pCi/d) intake from local food products.

Therefore, once the concentration of radionuclides has been determined for the foods and soils, the assumed diet becomes very important for estimating the pCi/d which will be ingested. In the past, the diet we constructed was based on literature reports and limited direct observation. More recently, however, the Micronesian Legal Services Corp. (MLSC) conducted a medical and dietary survey of the Enewetak people at Ujelang Atoll.

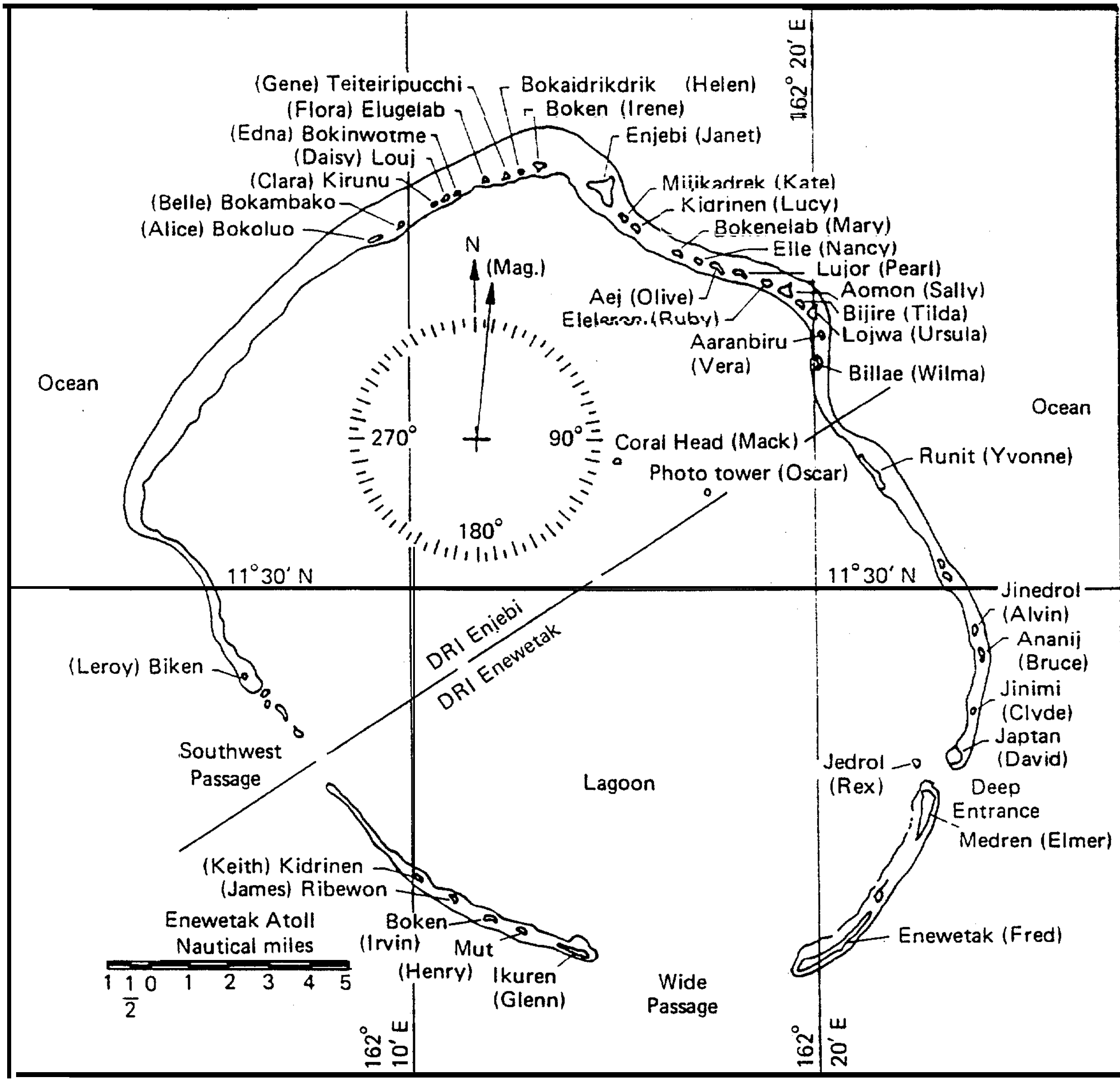

FIG. 1. Map of Enewetak Atoll.

The results are given in Appendix C. Because this is the most direct information available on the Enewetak people's dietary habits, we have used the results in our assessment, even though it is not certain to what extent resettlement at Enewetak Atoll will change the dietary habits of the people. In the next few years we hope to develop a dietary model based on direct observation of the people who are now residing on Enewetak Atoll. However, not until an abundance of locally grown foods becomes available and the lifestyle stabilizes will we be able to narrow the dietary uncertainties.

It is very important to emphasize again how dependent the estimated doses are on the dietary habits which are assumed.

DATA BASES

The exposure pathways for persons resettling Enewetak Atoll consist of two major categories: external and internal exposure.

The specific pathways in each category are:

1. External exposure
   a. Natural background
   b. Man-made gamma and beta rays
2. Internal exposure
   a. Radionuclides in terrestrial foods
   b. Radionuclides in marine foods
   c. Radionuclides in drinking water
   d. Radionuclides inhaled.

The natural background at the atoll is 3.5 μ R/h (microroentgen per hour) or 22 mrem/y (milliroentgen equivalent, m a n per year) and results primarily from cosmic radiation. The natural background is not included in the doses presented in this paper.

EXTERNAL EXPOSURE—IN SITU MEASUREMENTS

External exposure rates for ^{137}Cs and ^{60}Co, as well as the surface concentration values for ^{241}Am (0 to 3 cm), were obtained from in situ measurements performed by EG&G, Inc., as part of the Enewetak Cleanup Project and are listed in Appendix A. These measurements were made with a planar, high purity, germanium (HPGe) detector having a surface area of 1 9 cm^2 and a thickness of 1.6 cm. The detector was suspended from a retractable pneumatic boom 7.4 m above ground. The boom was mounted to the rear of the Thiokol IMP—a small, lightweight, tracked vehicle modified and equipped to be a fully self-contained, mobile, data-acquisition and reduction system.

Quantitative data are obtained from in situ measurements by combining a theoretical calculation of the flux at the detector (as a function of source and source distribution) with an experimental calibration of the detector response to a given incident flux. Table 1 lists the conversion factors as a function of relaxation depth. A more detailed discussion of the calibration procedures for this methodology can be found in Appendix B.

With the exceptions of Bokinwotme (Edna) and Taiwel (Percy), IMP measurements of ^{137}Cs, ^{60}Co, and ^{241}Am were reported by the Desert Research Institute (DRI) for the islands Bokolu (Alice) through Billae (Wilma). IMP measurements of Bokinwotme

TABLE i. Conversion factors relating the net photopeak count rate (cps) for ^{137}Cs to source activity in the soil and to external exposure rate as a function of source distribution.

Relaxation depth $1/\alpha$ cm	z, cm	Average activity in the top Z cm $\frac{S_v^Z/\rho}{N_P}$, $\frac{pCi/g}{cps}$	Total activity per unit area $\frac{S_A}{N_P}$, $\frac{\mu Ci/m^2}{cps}$	External exposure rate at the 1-m level $\frac{\mu R/h}{cps}$
5	0	13	1.0	3.6
	5	8.2		
	10	5.6		
	15	4.1		
	25	2.6		
	40	1.6		
	60	1.1		
10	0	10	1.5	3.7
	5	7.9		
	10	6.3		
	15	5.2		
	25	3.7		
	40	2.5		
	60	1.7		
15	0	8.8	2.0	3.4
	5	7.5		
	10	6.4		
	15	5.6		
	25	4.3		
	40	3.1		
	60	2.2		

TABLE 2. Average external exposure rate for ^{137}Cs at 1 meter.

	All data (actual measurement results)					All data (<MDA replaced with MDA)[a]				
Island	N	^{137}Cs μR/h	σ μR/h	Low value μR/h	High value μR/h	N	^{137}Cs μR/h	σ μR/h	Low value μR/h	High value μR/h
Bokoluo (Alice)	64	29.3	14.53	3.6	63.3					
Bokombako (Belle)	43	35.80	15.80	0.9	62.8					
Kirunu (Clara)	25	18.28	10.75	3.3	42.8					
Louj (Daisy)	30	4.39	4.71	0.7	16.8					
Boken (Irene)	60	3.3	3.5	0	13.7					
Sand spit	19	0.42	0.11	0.25	0.65					
Enjebi (Janet)	980	10.2	5.27	-0.1	36.2	980	10.2	5.27	0.2	36.2
NE quadrant	272	10.3	5.7	-0.1	36.2	272	10.3	5.7	0.2	36.2
SE quadrant	285	8.86	3.3	1.1	22.1					
SW quadrant	128	8.8	4.47	0.6	19.8					
NW quadrant	295	12.0	6.8	0.5	29.5					
Mijikadrek (Kate)	21	5.0	3.03	0.4	10.8					
Kidrinen (Lucy)	28	6.09	4.13	0.2	14.0					
Bokenelab (Mary)	19	3.14	1.55	1.1	6.9					
Elle (Nancy)	47	6.76	1.76	2.1	10.1					
Aej (Olive)	54	5.09	1.79	1.2	8.7					
Lujor (Pearl)	155	4	1.7	1	7.7					
Eleleron (Ruby)	9	0.6	0.32	0.39	1.31					
Aomon (Sally)	142	2.0	2.1	0	15.2	142	2.21	2.1	0.2	15.2
West tip	63	2.71	3.03	0.2	14.8					
Bijire (Tilda)	58	2.29	0.74	0.4	4.2					
Lojwa (Ursula)	16	0.9	0.4	0.1	1.6					
Alembel (Vera)	57	1.68	0.74	0.2	2.8					
Billae (Wilma)	20	0.77	0.38	0.1	1.5	20	0.77	0.37	0.2	1.5

[a]MDA is 0.2 μR/h.

TABLE 3. Average external exposure rate for ^{60}Co at 1 meter.

	All data (actual measurement results)					All data (<MDA replaced with MDA)[a]				
Island	N	^{60}Co µR/h	σ µR/h	Low value µR/h	High value µR/h	N	^{60}Co µR/h	σ µR/h	Low value µR/h	High value µR/h
Bokoluo (Alice)	64	17.40	8.09	4.1	32.5					
Bokombako (Belle)	43	15.2	6.60	1.9	28.7					
Kirunu (Clara)	25	9.2	4.85	2.1	19.5					
Louj (Daisy)	30	7.02	5.60	0.4	20.8	30	7.02	5.60	0.5	20.8
Boken (Irene)	60	13	17.3	-3.4	104	60	13	17.3	0.5	104
Sand spit	19	2.03	0.81	0.6	3.6					
Enjebi (Janet)	965	3.3	3.03	-0.6	38.6	965	3.4	2.99	0.5	38.6
NE quadrant	259	4.2	3.3	-0.6	24.4	259	4.3	3.44	0.5	24.4
SE quadrant	285	2.2	0.9	-0.4	5.0			1.02	0.5	5.0
SW quadrant	128	3.1	4.9	0.5	38.6			5.12	0.5	38.6
NW quadrant	293	3.5	2.0	0.6	16.3			2.22	0.5	16.3
Mijikadrek (Kate)	21	1.9	1.09	0.4	3.5			1.08	0.5	3.5
Kidrinen (Lucy)	28	2.63	1.50	0.1	4.6			1.42	0.5	4.6
Bokenelab (Mary)	19	1.40	0.70	0.3	2.8			0.68	0.5	2.8
Elle (Nancy)	47	2.22	0.54	0.5	3.2					
Aej (Olive)	54	1.87	0.71	0.2	3.0			0.70	0.5	3.0
Lujor (Pearl)	155	7	6.6	1	36.4					
Eleleron (Ruby)	9	3.82	6.04	0.4	19.5			6.03	0.5	19.5
Aomon (Sally)	142	0.71	0.52	0.0	3.5	142	0.52	0.43	0.5	3.5
West tip	63	3.94	6.47	0.2	33.8			6.45	0.5	33.8
Bijire (Tilda)	58	0.72	0.31	0.3	1.4			0.27	0.5	1.4
Lojwa (Ursula)	16	0.3	0.1	0.1	0.5					
Alembel (Vera)	57	0.52	0.22	0.1	1.0			0.13	0.5	1.0
Billae (Wilma)	20	0.32	0.13	0.1	0.6	20	0.51	0.02	0.5	0.6

[a]MDA is 0.5 µR/h.

TABLE 4. Average surface soil concentration for ^{241}Am.

	All data (actual measurement results)					All data (<MDA replaced with MDA)[a]				
Island	N	^{241}Am pCi/g	σ pCi/g	Low value pCi/g	High value pCi/g	N	^{241}Am pCi/g	σ pCi/g	Low value pCi/g	High value pCi/g
Bokoluo (Alice)	64	21.8	12.3	3.4	52.6					
Bokombako (Belle)	43	24.0	9.2	3	39					
Kirunu (Clara)	25	9	3.7	4.4	17					
Louj (Daisy)	30	10.8	5.8	2.8	29.5					
Boken (Irene)	60	3.2	2.5	0.6	14.3					
Sand spit	19	1.28	0.42	0.5	2.3					
Enjebi (Janet)	1015	6.1	3.4	-0.7	19.1	1015	6.2	3.34	0.5	19.1
NE quadrant	302	6.8	4.2	0.1	17.4	302	6.8	4.2	0.5	17.4
SE quadrant	285	6.6	3.8	0.1	16.2	285	6.6	3.8	0.5	16.2
SW quadrant	128	5.5	3.9	0.4	14.2					
NW quadrant	300	5.0	4	-0.7	19.1	300	5.0	4	0.5	19.1
Mijikadrek (Kate)	21	7.3	5.5	1.3	19					
Kidrinen (Lucy)	28	12.7	9.1	0.7	27					
Bokenelab (Mary)	19	6.5	4.6	1.7	17.3					
Elle (Nancy)	47	11.8	4.2	2.6	22.3					
Aej (Olive)	54	6.4	4.5	1	23.2					
Lujor (Pearl)	155	6.3	3.8	1	22.3					
Eleleron (Ruby)	9	1.2	0.6	0.2	1.9	9	1.3	0.47	0.5	1.9
Aomon (Sally)	142	2.2	2.9	-0.2	16.9	142	2.3	2.8	0.5	16.9
West tip	63	1.3	1.4	0.0	5.4	63	1.4	1.3	0.5	5.4
Bijire (Tilda)	58	2.4	1.6	0.1	7.0	58	2.4	1.6	0.5	7.0
Lojwa (Ursula)	16	0.7	0.4	0.1	1.6					
Alembel (Vera)	57	2.6	1.2	0.4	5	57	2.6	1.2	0.5	5
Billae (Wilma)	20	1.2	0.8	0.1	2.6	20	1.4	0.63	0.5	2.6

[a] MDA is 0.5 pCi/g.

(Edna) and Taiwel (Percy) were not made. In Tables 2 and 3, the average external exposure rates are summarized in μR/h for ^{137}Cs and ^{60}Co, respectively. Average surface soil concentrations, in pCi/g, for ^{241}Am are summarized in Table 4. Two types of means are presented in each table—those computed with the actual measurement results and those computed by substituting the appropriate minimum detectable activity (MDA) value for all measurement results less than the MDA. Where no measurement results were less than the appropriate MDA, the latter type of mean is not computed. MDA values used in the mean calculations were provided to DRI by EG&G and are single-valued over the entire atoll. Results for Bokaidrikdrik (Helen) appear as the Boken (Irene) sand-spit entries because the sand spit is all of Bokaidrikdrik (Helen) that remains. Means for the quadrants of Enjebi (Janet) shown in Fig. 2 reflect the following allocations of the baseline data: north baseline to the northeast quadrant, east baseline to the southeast quadrant, south baseline and benchmark (point 0,0) to the southwest quadrant, and west baseline to the northwest quadrant. Entries from the west tip of Aomon (Sally) reflect results for the land mass created between Eleleron (Ruby) and Aomon (Sally) by the Pacific Area Cratering Experiment (PACE) tests. With the exception of the Billae (Wilma) ^{60}Co results, the difference between the two types of means for a given island and isotope does not exceed 16%. In fact, for the most part it is less than 7%. The Billae (Wilma) ^{60}Co means reflect the difference expected when a significant number of the measurement results are less than the MDA and the maximum observed is not significantly higher.

In our calculations of the external dose due to ^{137}Cs and ^{60}Co, we have used the mean values based on the actual measurements for the islands Enjebi (Janet) through Billae (Wilma). For Aomon (Sally) we have weighted the means for Aomon (Sally) and Aomon (Sally) west tip according to their respective areas: approximately 30 hectares for Aomon (Sally) and approximately 3.4 hectares for Aomon (Sally) west tip. In the case of the southern islands, Jinedrol (Alvin) through Kidrenen (Keith), we have used the results reported in Ref. 1 (p. 501): 0.2 μR/h for ^{137}Cs and 0.1 μR/h for ^{60}Co. Decayed from 1973 to 1979, the external exposure rates for ^{137}Cs and ^{60}Co among the southern islands are currently estimated at 0.174 and 0.0454 μR/h, respectively. To convert from exposure rates to dose equivalent rates, a factor of 6.24 mrem/y per μR/h was used (see Appendix A).

Beta doses have been measured on Enjebi (Janet) Island and Bokombako (Belle) Island at Enewetak Atoll.[3] The measurements were made at 1-m height using thermoluminescent dosimeters (TLD's) with varying thicknesses of aluminum absorbers. The "shallow doses" calculated for Enjebi (Janet) Island are approximately 1.1 rem in 30 y and for the southern islands the dose is 0.01 rem in 30 y. This shallow dose is received

⊙ Soil sample location

· Grid nodes, 50 meters on centers except for 85 meters on centers in N.W. quadrant

Notes: Oscar coordinates
"X" axis: N146,720
"Y" axis: E85779

Note: Two parties of Lomas and Nwenwiles agreed to this hypothetical line and did not stake it for this map & layout.

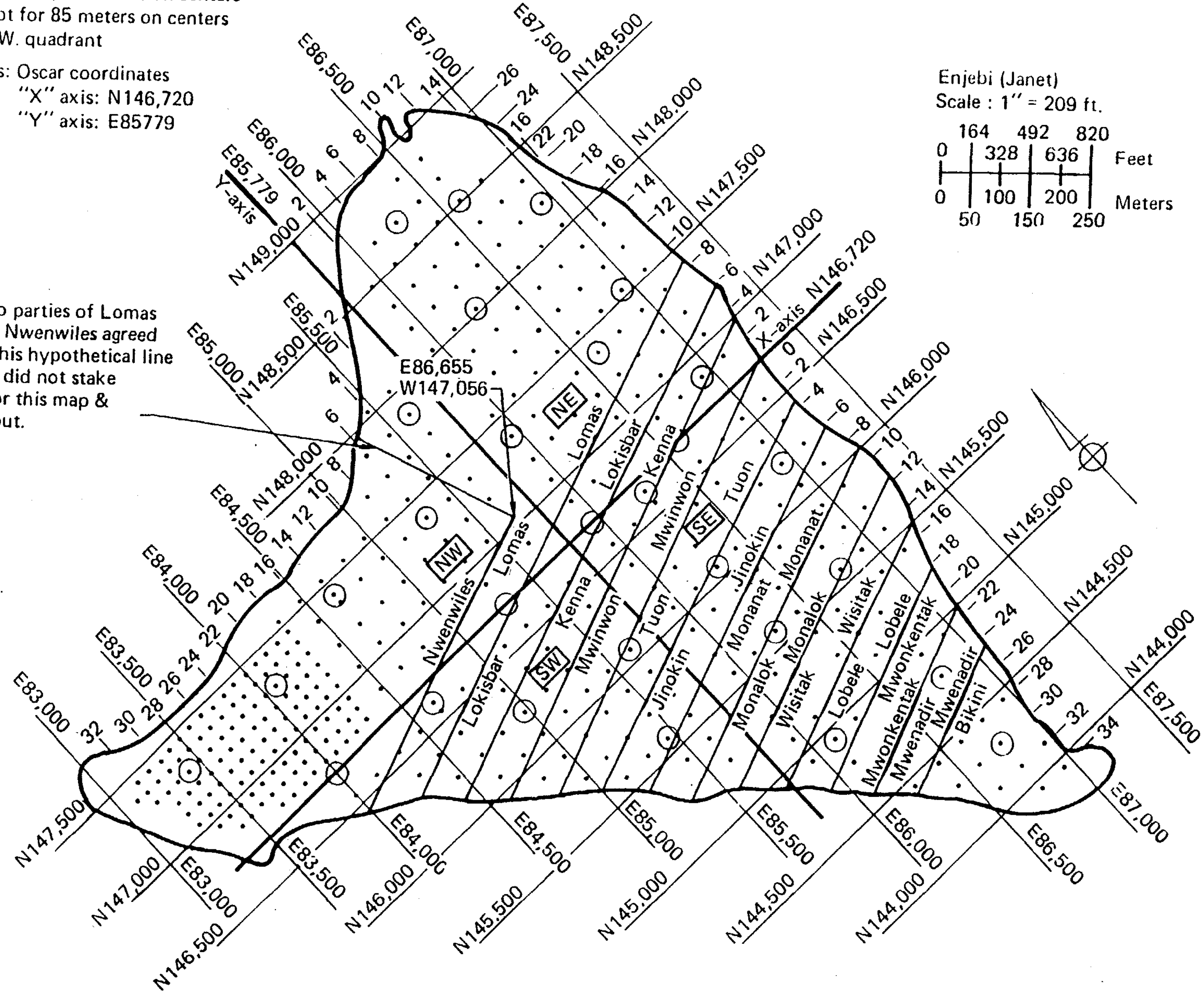

FIG. 2. Sampling grid and quadrants of Enjebi (Janet) Island with the family land holdings (watos) superimposed.

primarily by the surface and subsurface layers of skin (1-cm deep); deep doses from the external beta to organs such as gonads, bone marrow, and other internal organs are less than 1 mrem in 30 y. The shallow-dose contribution from the beta emitters cannot be summed with the bone and whole-body doses presented in this paper; if surface skin doses were to be considered independently, then the shallow dose from the beta emitters should be included. Because the beta particles have a short and defined range, any absorbing materials present, such as gravel, buildings, or clothing, will greatly reduce the external dose from beta emitters. Bremsstrahlung from the ^{137}Cs, $^{90}Sr/^{90}Y$ betas is of low energy and again readily absorbed by building material, etc.; in addition, the low-energy Bremsstrahlung is only a fraction of a percent of the total external gamma exposure.

INHALATION

Airborne concentrations of respirable $^{293+240}Pu$ and ^{241}Am are estimated from data developed in resuspension experiments conducted at Enewetak Atoll in February 1977 and at Bikini Atoll in May 1978. We briefly describe the resuspension methodology here; more detail and discussion can be found in a paper summarizing the studies at Enewetak and Bikini.[4]

The study conducted on Bikini Island in May 1978 provided a more complete set of data, following our preliminary studies on Enjebi (Janet) Island of Enewetak Atoll in February 1977. (Subsequent studies were conducted on Eneu Island of Bikini Atoll.) The Bikini Island study used extensive soil sampling and in situ gamma spectroscopy to determine isotope concentrations in soil and vegetation, various air-sampling devices to determine particle size distribution and radioactivity, and micrometeorological techniques to determine aerosol fluxes. Four simultaneous experiments were conducted: (1) a characterization of the normal (background) suspended aerosols and the contributions from sea spray off the windward beach leeward across the island, (2) a study of resuspension of radionuclides from a field purposely laid bare by bulldozers as a worst-case condition, (3) a study of resuspension of radioactive particles by vehicular and foot traffic, and (4) a study of personal inhalation exposure using small dosimeters carried by volunteers during daily routines. Less complete studies similar to (1) and (2) had been performed previously on Enjebi (Janet) and background studies similar to (1) were performed later on Eneu.

The "normal or background" mass loading measured by gravimetric methods for both atolls is approximately 55 μ g/m^3. The Bikini experiments show that 34 μg/m^3 of this total is due to sea salt, which is present across the entire island as a result of ocean, reef, and wind actions. The mass loading due to terrestrial origins is therefore about 21 $\mu g/m^3$. The highest terrestrial mass loading observed was 136 $\mu g/m^3$ immediately after bulldozing.

Concentrations of $^{239+240}Pu$ have been determined for: (1) collected aerosols for normal ground cover and conditions, i.e., normal conditions, in coconut groves, (2) for areas being cleared by bulldozers and being tilled, i.e., high-activity conditions, and (3) for stabilized bare soil, i.e., the cleared areas after a few days' weathering. The plutonium concentration in the collected aerosols changes relative to the plutonium concentration in surface oil for the various situations. We have defined an enhancement factor (EF) as the $^{239+240}Pu$ concentration in the collected aerosol mass divided by the $^{239+240}Pu$ surface soil (0-5 cm) concentration.

The EF obtained from standard Hi Vols for normal conditions is less than 1; the EF for the worst case, high-activity conditions is 3.1. Table 5 summarizes the observed EF at Bikini and Enewetak Atolls. The EF of less than 1 (EF < 1) for Hi Vol data for the normal, open-air conditions is apparently the result of selective particle resuspension in which the resuspended particles have a different plutonium concentration than is observed in the total 0-5 cm soil sample; in other words, the particle size and density, and the corresponding radionuclide concentration, is different for the normally resuspended material than for the total 0-5 cm soil sample. In addition, approximately 10% of the mass observed on the filter is organic matter, which has a much lower Pu concentration than the soil. Similarly the enhancement factor of 3.1 for high-activity conditions results from the increased resuspension of particle sizes with higher plutonium concentration than observed in the total 0-5-cm soil sample.

We have developed additional personal dosimeter enhancement factors (PDE factors) from personal dosimeter data. These data are normalized to the Hi Vol data for a particular condition and represent that enhancement that occurs around an individual due to his daily activities (different from the open air measurement made with the Hi Vols). These data are also summarized in Table 5. The total enhancement used to estimate the amount of respired Pu is the combination of the Hi Vol and personal dosimeter values. The effective enhancement used for normal conditions is 1.54 and for high-activity conditions is 2.9.

In the scenario adopted for the calculations we assume that a person spends 8 hours each day (h/d) in high-activity conditions and 16 h/d under normal conditions. Finally, a breathing rate of 23 m^3 per day (9.6 m^3 under high-activity conditions and 13.4 m^3 under normal-activity conditions)[5] and the surface soil concentration (0-5 cm) for each island are used to complete the calculation for Pu and Am intake via inhalation. The Am concentrations in the surface soil were measured in situ by high-resolution gamma spectroscopy (Appendices A and B). The Pu concentrations were estimated by using the

TABLE 5. Pulmonary deposition of plutonium ($^{239+240}Pu$) for worst-case and best-case conditions on Bikini.

Condition	Inhalation rate (m^3 h^{-1})	Dust aerosol (g m^{-3})	Soil Pu activity (aCi g^{-1})	Enhancement factor (EF)	Personal enhancement (PDE)	Respirable fraction (RESP)	Pulmonary disposition (aCi h^{-1})
Bare field, during tilling	1.04	136	15.3	3.10	0.92	0.24	1476
Stabilized field, heavy work	1.04	21	15.3	0.83	2.64	0.19	139
In and around houses, light work	0.83	21	15.3	0.83	1.86	0.19	78
Coconut grove light work	0.83	21	8.0	0.41	1.10	0.19	12
At roadside, one vehicle/hr[a]	.023	28	4.1	2.50	(1.0)	0.24	1.58 + BG

[a]Exposure to one, ten-second, median, vehicular dust-pulse, not including background (BG).

conversion ratio ($^{239+240}Pu/^{241}Am$) developed in the soil sampling program and listed in Table 6.

The ICRP lung model is used to estimate the lung and bone doses.[6] A pulmonary deposition of 0.3 is used in the inhalation lung model; at this time we feel it is conservative from a dose-assessment point of view because preliminary analysis of the particle size distribution for both normal and high-activity conditions at Bikini Atoll indicate that the pulmonary deposition would be less than 0.3 (Table 5). The gut transfer factors used for $^{239+240}Pu$ and ^{241}Am are 10^{-4} and 5×10^{-4} respectively, as recently suggested by the ICRP[7]; both Pu and Am are considered to be class W particles.

The dose contribution from the inhalation pathway is a major source of exposure to the transuranic radionuclides, but both the inhalation pathway and the transuranics contribute a minor portion of the total predicted doses over the next several decades.

TABLE 6. Ratio of the concentration in soil of $^{239+240}Pu$ to ^{241}Am for islands at Enewetak Atoll.

Island	$\frac{^{239+240}Pu}{^{241}Am}$
Mijikadrek (Kate)	1.7 ± 0.03
Kidrinen (Lucy)	1.6 ± 0.03
Bokenelab (Mary)	1.9 ± 0.13
Elle (Nancy)	1.7 ± 0.05
Aej (Olive)	1.7 ± 0.09
Eleleron (Ruby)	5.4 ± 0.39
Aomon (Sally)	2.4 ± 0.44
Bijire (Tilda)	1.8 ± 0.11
Lojwa (Ursula)	1.8[a]
Alembel (Vera)	1.5 ± 0.15
Billae (Wilma)	1.8 ± 0.09
Enjebi (Janet) northwest	4.3 ± 0.69/2.3 ± 0.4
Enjebi (Janet) northeast	2.3 ± 0.4
Enjebi (Janet) southwest	2.3 ± 0.4
Enjebi (Janet) southeast	2.3 ± 0.4
Southern islands	1.8[a]

[a]Assumed to be the same as Bijire (Tilda) and Billae (Wilma).

DRINKING WATER

The drinking water pathway contributes a very small portion of the total dose received via all pathways.[8-10] However, we have included an evaluation of this pathway to demonstrate its relative contribution and to complete the assessment of all major pathways.

The radionuclide concentration data used to evaluate the drinking water pathway are listed in Tables 7-9. Cistern water is preferred and most often used; however, well water is used when drought conditions exist. In addition to drinking water the Marshallese drink considerable quantities of coffee and "Kool-Aid (Malalo)" for which they again primarily use the cistern water. The total fluid intake involving the use of cistern water and well water was determined to be approximately 2 litres per day in the Ujelang Diet Survey (Appendix C).

TABLE 7. Measured and estimated radionuclide concentrations in meat and water for Enjebi Island.

	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
		pCi/g wet weight		
Pork	48[a]	0.07[a]	0.5×10^{-3}[a]	0.1×10^{-3}[a]
Chicken	1.2[a]	0.07[a]	0.5×10^{-3}[a]	0.1×10^{-3}[a]
Chicken eggs[b]	1.2	0.07	0.5×10^{-3}	0.1×10^{-3}
Groundwater[c]	90[d]	11[d]	6.7×10^{-3}[d]	2.9×10^{-3}
Cistern water[c]	1.8[e]	1.34[e]	1.7×10^{-2}[e]	0.85×10^{-2}

[a]Calculated from the concentration ratios developed from pig and chicken data from Bikini Island (W.L. Robison--to be published).

[b]Assumed to be the same as chicken.

[c]Units are pCi/l rather than pCi/g.

[d]From V. Noshkin et al., "Plutonium Radionuclides in the Groundwaters at Enewetak Atoll," International Atomic Energy Agency Symposium, Transuranium Nuclides in the Environment, IAEA-SM-199/33 Vienna, 1976.

[e]Assumed to be the same as Bikini Island Cistern Water; data from V.E. Noshkin et al., "Evaluation of the Radiological Quality of the Water on Bikini and Eneu Islands in 1975; Dose Assessment Based on Initial Sampling," Lawrence Livermore Laboratory, Report UCRL-51879, Part 4, 1977.

TABLE 8. Measured and estimated radionuclide concentrations in meat and water for southern islands.

	^{137}Cs	^{90}Sr	$^{239+240}Pu$	^{241}Am
		pCi/g wet weight		
Pork	0.52[a]	0.014[a]	0.3×10^{-5}[a]	0.9×10^{-6}[a]
Chicken	0.013[a]	0.014[a]	0.3×10^{-5}[a]	0.9×10^{-6}[a]
Chicken eggs[c]	0.013	0.014	0.3×10^{-5}	0.9×10^{-6}
Groundwater[d]	0.56[e]	0.09[e]	0.51×10^{-3}[f]	0.26×10^{-3}
Cistern water[d]	0.09[b]	0.1[b]	0.2×10^{-3}[f]	0.1×10^{-3}

[a]Calculated from concentration ratios developed from pig and chicken data from Bikini Island (W.L. Robison--to be published).

[b]Assumed to be the same as Kwajelein cistern water. Source of Kwajelein cistern data: V. Noshkin et al., Evaluation of the Radiological Quality of the Water on Bikini and Eneu Islands in 1975; Dose Assessment Based on Initial Sampling, Lawrence Livermore Laboratory, Livermore, CA, UCRL-51879, Part 4 (1977).

[c]Assumed to be the same as chicken meat.

[d]Units are pCi/litre rather than pCi/g.

[e]V. Noshkin, Lawrence Livermore National Laboratory, Livermore, CA, private communication (Memo August 28, 1974).

[f]From V. Noshkin, "Plutonium Radionuclides in the Groundwaters at Enewetak Atoll", in International Atomic Energy Agency Symposium, Transuranium Nuclides in the Environment, IAEA-SM-199/33 Vienna, 1976.

TABLE 9. Measured and estimated radionuclide concentrations in meat and water for Aomon (Sally) and Bijire (Tilda).

	^{137}Cs	^{90}Sr	$^{239+240}$Pu	^{241}Am
		pCi/g wet weight		
Pork	8.4[a]	0.01[a]	0.14×10^{-3} [a]	0.3×10^{-4} [a]
Chicken	0.21[a]	0.01[a]	0.14×10^{-3} [a]	0.3×10^{-4} [a]
Chicken eggs[b]	0.21	0.01	0.14×10^{-3}	0.3×10^{-4}
Groundwater[c]	d	d	d	d
Cistern water[c]	0.21[e]	0.36[e]	1.6×10^{-3} [f]	0.1×10^{-3} [f]

[a]Calculated from pig and chicken data from Bikini Island (W.L. Robison--to be published); Bikini meat data is multiplied by the ratio of the Aomon/Bijire radionuclide soil concentration to the Bikini Island soil concentration to develop the Aomon/Bijire meat concentration.

[b]Assumed to be the same as chicken meat.

[c]Units are pCi/litre rather than pCi/g.

[d]The lens water on Aomon/Bijire is not suitable chemically for drinking; the lens water is extremely brackish and a fresh water layer is non-existent--V. Noshkin personal communication.

[e]Assumed to be the same as Eneu Island Cistern Water--Eneu Island data from V. Noshkin report to DOE HQ.

[f]From V. Noshkin, "Plutonium Radionuclides in the Groundwaters at Enewetak Atoll", International Atomic Energy Agency Symposium, Transuranium Nuclides in the Environment, IAEA-SM-199/33 Vienna, 1976. For Aomon (Sally) the cistern water is assumed to have the same concentration as the catchment water contained in small craters in the PACE excavation area.

TERRESTRIAL FOODS

Soil Radionuclide Concentrations

The soil sampling program was begun in February of 1979 at Enewetak Atoll. This program was conducted by NVOO with technical direction from LLNL. A 50-m grid was established on each of the islands Bokoluo (Alice) through Billae (Wilma), i.e., the northwest through the northeast and east side of the atoll. Soil profile samples were collected at each 50-m grid point.

All soil profile samples were collected for the following increments: 0-5 cm, 5-10 cm, 10-15 cm, 15-25 cm, 25-40 cm, and 40-60 cm. We have found that 40-cm depth encompasses most of the active root zone of the subsistence crops that we have observed in the northern Marshall Islands. A trench was dug with a backhoe at each 50-m grid point and samples were collected down the sidewall of the trench, after the sidewall was scraped to avoid any possible contamination from the digging process. The 0-5 cm sample was collected from a surface area about 25 cm on a side. The area was then expanded by about 10 cm on each side and cleared to a depth of 5 cm. The upper surface (1-2 cm) of this enlarged area (35 cm × 35 cm) was then cleared to ensure that neither surface soil nor soil from a preceding increment had fallen onto the next increment to be sampled. The next sample was then taken from the entire depth of the increment (i.e., 5-10 cm) from an area about 25-cm square within the enlarged region (35 cm × 35 cm). This procedure was repeated until the final increment of 40-60 cm had been collected. A total of approximately 500-900 g of soil was collected for each profile increment.

The soil samples were dried and ball-milled into a fine powder. Samples were then analyzed by gamma spectroscopy to determine the ^{137}Cs and ^{241}Am concentrations and by wet chemistry procedures to determine the concentration of ^{90}Sr, and in some cases, $^{239+240}Pu$, ^{241}Am, and ^{241}Pu. Gamma spectroscopy of the soil samples for ^{137}Cs and ^{241}Am was accomplished using high-resolution, solid-state, germanium-diode systems. Strontium-90, $^{239+240}Pu$, ^{241}Am, and ^{241}Pu were analyzed by wet chemistry procedures by Eberline Instrument Corporation. The NVOO was responsible for the quality control aspects of the analytical project.[11]

Radionuclide concentrations for the profile for 0-5 cm, 0-10 cm, 0-15 cm, 0-25 cm, 0-40 cm, and 0-60 cm were calculated by LLNL using equal weights for each 5-cm increment. The island average for each depth profile (i.e., 0-5 cm, 0-25 cm, 0-40 cm, etc.) was calculated by averaging the results for each profile taken on the island. The results are summarized in Appendix D.

Concentration Ratios

Very few locally grown crops are available at Enewetak Atoll. The test plots established on Enjebi (Janet) Island have provided data for that island for papaya, banana, sweet potatotes, and squash; other than these test plots, the available trees are limited to one or two isolated coconut and Pandanus trees on four or five islands in the northern section of the atoll. Coconut trees are available in the southern half of the atoll but the radionuclide concentrations are very low and it is difficult to develop reliable data.

As a result of the scarcity at Enewetak of locally grown foods that can be directly analyzed, we have developed concentration ratios between food products and soil (pCi/g wet weight in food per pCi/g dry weight in soil) for each radionuclide; we used data obtained from our test plots on Enewetak and Bikini Atolls, from the coconut trees on Bikini Atoll which are now producing fruit, and from the few isolated trees on four islands at Enewetak Atoll. The mean, standard deviation, median, and the high and low values for the concentration ratios developed from samples collected through November 1978 are listed in Tables 10-13 for ^{137}Cs, ^{90}Sr, $^{239+240}Pu$, and ^{241}Am, respectively. The concentration ratios are developed from soil profiles taken to a depth of 40 cm through the root zone of the plants being sampled. This depth is used because we observe that it encompasses most of the active root zone of the subsistence plants we have studied on Enewetak and Bikini Atolls. A report on the root activity[12] of large mature coconut

TABLE 10. Concentration ratio (CR) estimated over a 0- to 40-cm soil profile for subsistence crops for ^{137}Cs.

Food item	Number	CR[a]	σ	High value	Median	Low value
Coconut meat	33	6	4.1	25	4.3	1.1
Coconut fluid	11	3				
Breadfruit	9	0.54	0.48	1.6	0.38	0.12
Pandanus fruit	5	3.9	3.8	9.6	2.8	0.18
Papaya	38	2.3	1.9	13	0.53	0.1
Squash	12	4.3	1.8	8.2	4.3	1.8
Banana	5	0.14	0.093	0.28	0.14	0.075
Watermelon	17	1.6	1.2	4.3	1.4	0.12

[a] pCi/g fruit wet weight per pCi/g soil dry weight.

TABLE 11. Concentration ratio (CR) estimated over a 0- to 40-cm soil profile for subsistence crops for ^{90}Sr.

Food item	Number	CR[a]	σ	High value	Median	Low value
Coconut meat	26	9.8(-3)	1.2(-2)	7.3(-2)	5.1(-3)	8.6(-4)
Coconut fluid	11	1.8(-3)				
Breadfruit	9	0.07	0.058	0.15	0.55(-2)	5.8(-3)
Pandanus fruit	3	0.46	0.22	0.69	0.42	0.26
Papaya	15	4.1(-2)	3.5(-2)	1.1(-1)	5.8(-2)	2.5(-2)
Squash	5	2.4(-2)	1.2(-2)	4.0(-2)	2.8(-2)	8.8(-3)
Banana	3	9.6(-3)	5.5(-3)	1.5(-2)	7.7(-3)	4.4(-3)
Watermelon	8	1.8(-2)	7.9(-3)	2.9(-2)	1.5(-2)	7.2(-3)

[a] pCi/g fruit wet weight per pCi/g soil dry weight.

TABLE 12. Concentration ratio (CR) estimated over a 0- to 40-cm soil profile for subsistence crops for $^{239+240}Pu$.

Food item	Number	CR[a]	σ	High value	Median	Low value
Coconut meat	22	9.7(-5)	1.3(-4)	4.8(-4)	3.1(-5)	1.7(-6)
Coconut fluid	11	1.2(-5)				
Breadfruit	8	1.5(-5)	1.6(-5)	4.7(-5)	1.2(-5)	1.6(-6)
Pandanus fruit	3	4.3(-5)	4.2(-5)	8.9(-5)	3.3(-5)	6.4(-6)
Papaya	16	3.6(-5)	4.8(-5)	1.8(-4)	2.4(-5)	3.3(-7)
Squash	5	1.9(-5)	1.5(-5)	4.0(-5)	1.2(-5)	3.3(-6)
Banana	3	2.4(-5)	3 (-5)	6.4(-5)	1.9(-5)	7.2(-6)
Watermelon	8	4.0(-5)	3.3(-5)	8.9(-5)	4.3(-5)	7.1(-6)

[a] pCi/g fruit wet weight per pCi/g soil dry weight.

, TABLE 13. Concentration ratio (CR) estimated over a 0- to 40-cm soil profile for subsistence crops for ^{241}Am.

Food item	Number	CR[a]	σ	High value	Median	Low value
Coconut meat	15	1.4(-4)	2.7(-4)	1.1(-3)	3.7(-5)	4.1 (-6)
Coconut fluid	11	1.1(-5)				
Breadfruit	5	1.7(-5)	2.2(-5)	5.6(-5)	6.5(-6)	2.6(-6)
P sndanus fruit	2	1.2(-4)	1.5(-4)	2.3(-4)	1.2(-4)	1.0(-5)
Papaya	i3	1.4(-4)	2.8(-4)	1.0(-3)	9.3(-5)	6.1(-7)
Squash						
Banana	2	1.2(-5)	1.3(-5)	2.2(-5)	- .	3.1(-6)
Watermelon	7	2.7(-5)	2.7(-5)	7.8(-5)	2.8(-5)	2.5(-6)

[a] pCi/g fruit wet weight per pCi/g soil dry weight.

and banana trees in other tropical regions showed most of the activity in the O-60 cm depth, although root activity did vary with age and species; the report is consistent with our observations of the physical location of the root zone at Enewetak and Bikini atolls.

Food Radionuclide Concentrations

As a result of the paucity of available food products with which to directly determine the radionuciide concentrations in locally grown foods at the atoll, we have predicted the radionuclide concentrations in foods for each island by multiplying the average island soil concentrations. for the O-40 cm depth, as discussed above, by the concentration ratios developed for the O-40 cm profile, as discussed above. These predicted radionuclide concentrations in foods are then used in conjunction with the assumed average diets and dose models to develop the dose assessment for alternate living patterns. The data in Appendix D and in Tables 10-13 can be used to determine the concentration of each radionuclide in each food product. Where direct measurement data of radionuclide concentration in fish, animals, or plants were available, they were used.

MARINE FOODS

The concentrations in marine fish, shellfish, and invertebrates are listed in Table 14 along with the sources of data. Much of the data were abstracted from the 1973

TABLE 14. Measured and estimated radionuclide concentrations in marine species, and birds and coconut crabs at Enewetak Atoll.

	pCi/g wet weight			
	^{137}Cs	^{90}Sr	$^{239+240}Pu$	^{241}Am
Fish[a] (reef)	0.11[b]	0.021[b]	2.4×10^{-3}[c]	0.52×10^{-3}[c]
Fish (pelagic)	0.77	0.021	2.4×10^{-3}	0.52×10^{-3}
Shellfish[d]	0.0025'	0.0038[b]	0.0011[b]	0.0015[b]
Clams[e]	0.11[d]	0.0057[b]	0.044[b]	0.0095[f]
Birds	0.024[b]	0.011[b]	2.4×10^{-3}[g]	0.52×10^{-3}[g]
Bird eggs	0.029[b]	0.19[b]	2.4×10^{-3}[g]	0.52×10^{-3}[g]
Crabs[h]	1.7[b]	0.43[b]	8.8×10^{-4}[b]	4.4×10^{-4}[i]

[a]Includes all reef fish and pelagic fish. Radionuclide concentrations are assumed to be the same for all species.

[b]Enewetak Radiological Survey, NVO-140, 1973, Vol. 1.

'Victor Noshkin--to be published. The concentrations are for muscle plus the skin.

[d]Includes lobster and marine crabs which are assumed to have the same radionuclide concentration in tissue.

[e]Includes the different species and both muscle tissue and hepatopancreas.

[f]Calculated using the fish $^{239+240}Pu/^{241}Am$ ratio.

[g]Assumed to be the same as fish muscle.

[h]Includes coconut crabs and land crabs both of which are assumed to have the same radionuclide concentrations in tissue.

[i]Calculated assuming the average $^{239+240}Pu/^{241}Am$ ratio for all northern islands is 2.

Radiological Survey Report.' The $^{239+240}Pu$ and ^{241}Am data are recently developed by V.E. Noshkin and are lower than previously published values; these fish data, when compared with the corresponding atoll lagoon-water concentrations, are more in line with other published concentrations ratios (pCi/g in fish per pCi/g in water). The previously published transuranic data are anomalous and we feel the current data are based on reliable collection and analytical methods and they are therefore used in this evaluation. Other assumptions have beenidentifiedin the footnotes of the table.

DIET

The estimated average diet used in the dose assessment is a very critical parameter; doses will scale directly with the quantity of locally grown foods that is consumed. Therefore, an accurate estimate of the average daily consumption rate of each food item is important.

The diet used in this dose assessment was recently developed from a survey conducted of the Enewetak people on Ujelang Atoll by the Micronesian Legal Services Corp. (MLSC). The field notes from Mr. Michael Pritchard, who conducted the survey for MLS, are attached in Appendix C along with a sample questionnaire. A detailed summary by LLNL of that survey is also included in Appendix C.

The school teacher on Ujelang Atoll joined Mr. Pritchard and MLS staff in conducting the survey. Approximately 25% of the Ujelang population were interviewed. The breakdown by age group was:

36	Adult males
36	Adult females
19	12 through 17 y of age
37	4 through 11 y of age
16	0 through 3 y of age

A total of 144 persons were interviewed, 2 females failed to complete the dietary questionnaire.

Some people were away from the atoll at the time of the interview and so selection was limited to those households where several people were available. The households were selected at random from the available pool with constraints to meet the goals outlined in Chart 2 of Appendix C.

Throughout our discussions of diet and estimated dose, three expressions are used extensively: imports available, imports unavailable, and local foods. "Imports available" conditions are those conditions existing when field ships arrive on schedule and imported and local foods are both available. "Imports unavailable" implies a condition where there is an absence of foods from outside. "Local foods" is an LLNL expression for the locally grown foods of the Ujelang Survey. Under normal conditions, imported foods are preferred over local food items. When imports are <u>unavailable</u> it is assumed local foods are the <u>only</u> source of dietary intake. This condition is then projected over a lifetime.

Data on the dietary preferences of the Enewetak people were provided to LLNL in three parts: (1) Household Survey results for the Ujelang/Japtan population, (2) Individual Medical and Diet Survey (IMD) results for 144 persons, and (3) a memorandum from Michael Pritchard of the MLSC (subject: Report and Field Notes on Ujelang Food Survey, April 22 to May 9, 1979). This report, with minor editing for style but with content unchanged, is attached in Appendix C. According to Pritchard, "the household survey met three major needs: it provided in descriptive fashion an account of the eating habits for the entire population of Ujelang; it provided data on certain special diets for certain types of individuals such as pregnant women; and served as a census document for locating individuals for the IMD survey." The completed IMD questionnaires provided, when known, each surveyed individual's name, age, sex, height, weight, sickness frequency, prior medical treatment, x-ray history, radiation therapy history, parental data, and preference for various local and imported foods for conditions where imported foods were both available and unavailable. Consumed quantities of each food item preferred were expressed in volume equivalents of a 12-oz beverage can per day, week, and month. Pritchard's memorandum provided insight into such things as the overall survey procedure, the estimated uncertainties in some reported values, the preferences in preparation and consumption of many food items, and the can conversion data (grams of food per 12-oz can) for some food items.

We have used the dietary results of the IMD questionnaires to determine the mean intakes in grams per day (g/d) of local and imported foods when imports are available and unavailable for adult males, adult females, and children in the 0- through 3-, 4- through 11-, and 12- through 17-y ranges. However, before presenting the results for mean intakes, a brief description of the procedure is in order.

Initially, each questionnaire was examined to determine the total number of individual food items indicated as preferred. Once this was done, we established a standard computer-card format for all the food items and then transferred each individual's monthly dietary preferences to cards. Where an individual showed no preference (response) for a specific food item, a blank field appears on the card. In those cases where an individual showed a preference for a specific organ of domestic meat (pork or chicken), they have been so recorded. However, in those cases where more than one organ was preferred, but no relative preference given, we have arbitrarily recorded them under the liver.

Concurrently, we developed the can conversion data necessary to convert the 12-oz cans/mo into g/d. The methods used to determine these conversions were many and varied. In some cases, 12-oz cans were packed with the specific food item and weighed; in others, the weights for canned or packaged foods were used. In still others, like some marine foods, densities in g/cm^3 were computed and used for the conversion. Some assumptions were also made where a specific food item was unavailable. Tables 15 and 16 summarize the can conversion data developed for the local and imported foods, respectively. In each table, the foods have been grouped under the major categories in

TABLE 15. Summary of can conversion data for imported food items for the Ujelang Survey.

Food type	Grams per 12-oz can
Fish	
Reef fish	219
Tuna	290[a]
Mahi Mahi	250[a]
Shellfish	
Marine crabs	362[b]
Lobster	354[c]
Clams	
Clam muscles	368[d]
Trochus	368[e]
Tridacna muscle	368,
Tridacna viscera	368[e]
Jedrul	368[e]
Crabs	
Coconut crabs	362[f]
Land crabs	362[f]
octopus	364[g]
Turtle	368[g]
Domestic meat	
Chicken muscle (raw)	369
Chicken liver (raw)	409[h]
Chicken gizzard (raw)	369[1]
Pork muscle (raw)	369[i]
Pork kidney (raw)	367[i]
Pork liver (raw)	409[h]
Pork heart	369
Wild birds	
Bird muscle (raw)	369[1]
Bird viscera (raw)	409[1]
Eggs	
Bird eggs	364[k]
Chicken eggs	364
Turtle eggs	364[k]
<u>Pandanus</u>	
<u>Pandanus</u> fruit	119 (112)[1]
<u>Pandanus</u> nuts	340[m]
Coconut fluid	
Coconut juice	355
Coconut milk	355
Tuba/jekeru	355
Coconut meat	
Young coconut	300[a]
Middle age coconut	210 (185)[a]
Old coconut	125[a]
Marshallese cake	54p

TABLE 15. Continued.

Food type	Grams per 12-oz can	Food type	Grams per 12-oz can
Papaya	380	Aqueous liquids	
Squash (uncooked)	232	Rainwater	355
Pumpkin (uncooked)	232	Well water	355
Banana	252	Malolo	355[o]
Watermelon	253	Coffee/tea	355[o]
Arrowroot	242 (220)[a]		
Citrus	319		

[a]Weight reported by Pritchard.

[b]Calculated from density of Dungeness crab.

[c]Calculated from density of lobster tail.

[d]Calculated from density of cherrystone clam muscle.

[e]Assumed the same as clam muscle.

[f]Assumed the same as marine crab.

[g]Calculated from density of squid. Assumed the same.

[h]Value is for beef liver. Assumed the same.

[i]Assumed the same as chicken muscle.

[j]Value is for beef kidney. Assumed the same.

[k]Assumed the same as chicken eggs. Value is mean for raw (393 g/can) and scrambled (355 g/can).

[l]Value is for raw Pandanus less fibrous strings. Calculated from data reported by Pritchard.

[m]Value is for roasted peanuts and cashews. Assumed the same.

[n]Calculated from weights reported by Pritchard. Broiled (255 g/can - 60 % consumption).

[o]Assumed the same as water.

[p]Quantity of coconut meat in Marshallese cake. Calculated from data reported by Pritchard.

TABLE 16. Summary of can conversion data for imported food items for the Ujelang Survey.

Food item	Grams per 12-oz can	Food item	Grams per 12-oz can
Baked bread	130 (90)[a]	Carbonated drinks	355[c]
Fried bread	115 (186)[b]		
Pancakes	166	Canned juices	
Cake	141	Orange juice	355[c]
Rice (cooked)	343	Tomatoe juice	355[c]
Instant potatoes (cooked)	355	Pineapple juice	355[c]
Sugar	350[c]	Other canned juice	355[c]
Canned meats and poultry		Milk products	
Canned chicken	341[c]	Evaporated milk	355[c]
Corned beef	340[c]	Powdered milk	355[c]
Spam	340[c]	Whole milk	355[c]
		Canned butter	340[e]
Canned fish			
Canned mackeral	340[c]	Onion	235
Canned sardines	339[c]	Canned vegetables	340[c]
Canned tuna	340[c]	Baby food	341[c]
Canned salmon	341[c]	Cocoa	355[c]
Other canned fish,	340[c]	Ramen noodles(cooked)	364
Other meat, fish, or poultry	340[d]	Candy	200

[a]Weight reported by Pritchard.

[b]Mean weight for two forms of fried bread reported by Pritchard. Round doughnut holes (151 g/can) and a heavier version (2200 g/can). Both of equal popularity.

[c]Weight in grams from grocery store containers.

[d]Assumed the same as canned meat, fish, and poultry.

[e]Weight reported is for lard.

our dietary means. We have included the results reported by Pritchard, where appropriate, and have made liberal use of footnotes to clarify the sources of data. In terms of accuracy, our can conversion data have some limitations. First, we were not able to obtain samples of all foods. Second, our data for fish, shellfish, clams, crabs, octopus, turtle, domestic meat, and wild birds are raw weights, whereas some of these foods are only consumed after some form of cooking. Third, we have assumed an average for raw and scrambled eggs since Pritchard reports that bird eggs are "usually eaten scrambled," chicken eggs are not described, and turtle eggs are "usually eaten raw or scrambled." Fourth, pumpkin (and undoubtedly squash) is consumed cooked rather than uncooked. Fifth, there may be other foods that are consumed in a different form than we reported. Finally, the differences between the LLNL and Pritchard values for a specific food item could reflect differences in food form (e.g., raw or cooked), can packing, or both. To be more precise, the can conversion data would require detailed weighing of each food item in the form consumed by the Enewetak people.

The final step in our procedure was to analyze the local food data with a computer code specifically developed for that purpose. For each specific food item and major category identified, the mean intake, standard deviation, high intake, low intake, and percent responding (i.e., N/N_0 where N is the number responding and N_0 is the total) in the sample were determined. Similar methods were used to develop the summary of the imported portion of the diet.

Tables 17 through 21 summarize our dietary-intake results for local foods when imports are available and unavailable for adult males (18-80 y), and adult females (18-78 y), and children in the 0- through 3-, 4- through 1 1-, and 12- through 17-y ranges, respectively. Results for imported foods (normal conditions only) are summarized in Tables 22 through 24.

In a summary of a survey conducted during July and August 1967 at Majuro Atoll[13] the average coconut use was reported to be approximately 0.5 coconut per day per person. This included young drinking coconuts, old nuts used for grated meat and pressed for small volumes of milk, and sprouting nuts used for the sweet, soft core. Recent data from Eneu Island shows that an average drinking coconut contains 325 ml of fluid (σ = 125 ml) so that even if the entire average coconut use of 0.5/d were all drinking nuts the average daily intake would be about 160 g/d. This is in agreement with the results from the Ujelang Survey.

A recent report, yet to be published, by Dr. Jan Naidu of Brookhaven National Laboratory[14] (BNL) became available after our report had essentially been completed. The BNL report discusses dietary habits and living patterns at several atolls in the Northern Marshall Islands other than Ujelang and Enewetak. The data were obtained by the authors from personal observations while living with the Marshallese and from answers to questionnaires.

The observations and questionnaires were directed more toward estimating the food prepared for a family rather the amount of food actually consumed; because food is shared and some food prepared is fed to pigs or chickens, these two are not necessarily the same. In the draft report the authors state:

"This attempt then to seek estimates from the islanders themselves concerning the actual amounts of local foods in the contemporary diet should be used not as an answer to the question of what constitutes the "typical average" but rather as a feasibility study on the possibility of obtaining the desired information in this way. We feel that the averages which we obtained from the interview study are for one reason or another consistently overestimated and should be considered maximum estimates or overestimates until such time as further study proves them accurate or (more likely) provides average factors for food sharing and wasting which can be folded into the study to provide more accurate, reduced estimates."*

The diet patterns are divided into 3 categories representing 3 types of communities:

Community A:

a. Maximum availability of local foods
b. Highly depressed local economy—living within income provided by selling copra
C. Low population
d. Little or no ability to buy imported food.

Community B:

a. Low availability of local foods—except fish (since it can form as much as 33% of the total diet) as a result of excellent fishing in the area
b. Overpopulated—resulting in low availability of local foods
C. A good supply of imported foods (supply boat comes in every 2-3 weeks) and readily available jobs.

Community C:

a. Low availability of local foods, even fishing is poor
b. Large government food program
C. Overpopulated
d. A good supply of imported foods and availability of cash to buy them.

*Underlined for emphasis.

TABLE 17. Dietary intake in g/d for local food items in the Ujelang Survey for adult males.

Food	Imports available						Imports unavailable					
	Number	Mean	σ	Low value	High value	Proportion of nonzeros	Number	Mean	σ	Low value	High value	Proportion of nonzeros
Fish	36	41.5	34.7	7.9	194.6	1.00	36	89.3	67.0	2.7	341.7	1.00
Shellfish	36	5.8	7.7	0.0	28.4	0.53	36	27.6	46.1	0.0	202.9	0.92
Clams	36	9.3	15.0	0.0	60.8	0.50	36	53.1	67.4	0.0	276.0	0.97
Crabs	36	3.4	7.3	0.0	38.9	0.44	36	14.1	31.0	0.0	181.0	0.86
Octopus	36	2.6	5.2	0.0	26.1	0.56	36	12.1	21.8	0.0	91.0	0.86
Turtle	36	3.7	6.9	0.0	26.4	0.72	36	7.6	13.0	0.0	52.8	0.94
Domestic meat	36	18.6	22.0	0.0	92.7	0.92	36	32.0	36.9	1.0	145.4	1.00
Wild birds	36	8.8	12.6	0.0	41.4	0.42	36	25.4	25.3	0.0	108.6	0.83
Eggs	36	7.9	11.9	0.0	45.3	0.64	36	15.3	14.2	0.0	58.2	0.92
Pandanus	36	2.7	3.5	0.0	13.1	0.44	36	27.9	33.5	0.0	112.0	0.97
Breadfruit	36	12.8	12.7	0.0	54.2	0.75	36	57.6	51.4	7.8	217.0	1.00
Coconut fluid	36	98.6	82.2	0.0	367.8	0.97	36	167.7	114.3	51.0	380.4	1.00
Coconut meat	36	32.5	30.1	3.9	146.5	1.00	36	125.1	111.5	33.0	610.0	1.00
Papaya	36	1.6	5.4	0.0	27.2	0.14	36	6.8	11.2	0.0	38.0	0.36
Squash	0	-	-	-	-	-	0	-	-	-	-	-
Pumpkin	23	0.2	0.8	0.0	3.9	0.04	23	0.7	2.0	0.0	8.4	0.13
Banana	36	0.0	0.0	0.0	0.0	0.0	36	0.0	0.0	0.0	0.0	0.0
Watermelon	0	-	-	-	-	-	0	-	-	-	-	-
Arrowroot	36	2.3	6.9	0.0	31.5	0.17	36	64.8	75.6	0.0	220.0	0.97
Citrus	36	0.0	0.0	0.0	0.0	0.0	36	0.0	0.0	0.0	0.0	0.0
Aqueous liquids	36	915.0	570.4	228.4	2751.2	1.00	36	548.6	447.4	0.0	2130.0	0.97
TOTAL	36	1167.1	597.0	333.9	3188.4	1.00	36	1275.4	553.3	379.2	2849.4	1.00

TABLE 18. Dietary intake in g/d for local food items in the Ujelang Survey for adult females.

Food	Imports available						Imports unavailable					
	Number	Mean	σ	Low value	High value	Proportion of nonzeros	Number	Mean	σ	Low value	High value	Proportion of nonzeros
Fish	34	41.5	28.8	3.6	118.5	1.00	34	90.1	81.1	7.0	409.6	1.00
Shellfish	34	5.1	9.3	0.0	34.8	0.47	34	25.2	42.3	0.0	231.7	0.85
Clams	34	8.9	14.1	0.0	52.8	0.65	34	43.6	48.4	0.5	197.2	1.00
Crabs	34	3.1	7.4	0.0	39.0	0.32	34	12.5	31.2	0.0	181.0	0.77
Octopus	31	4.5	8.3	0.0	26.1	0.45	31	24.5	50.5	0.0	273.0	0.87
Turtle	31	4.3	9.5	0.0	49.1	0.58	30	8.9	12.0	0.0	49.1	0.93
Domestic meat	34	21.2	52.4	0.0	292.9	0.74	34	34.5	98.1	1.0	576.6	1.00
Wild birds	34	4.2	8.7	0.0	38.2	0.29	34	17.8	23.6	0.0	107.0	0.88
Eggs	34	10.7	32.2	0.0	182.0	0.38	34	55.8	152.5	0.0	791.7	0.91
Pandanus	34	9.2	16.6	0.0	82.1	0.68	34	32.5	32.3	0.0	114.3	0.94
Breadfruit	34	27.2	38.1	0.0	182.3	0.82	34	93.1	94.0	7.2	325.5	1.00
Coconut fluid	34	141.8	122.0	25.4	520.7	1.00	34	216.6	179.3	28.4	710.0	1.00
Coconut meat	34	63.3	98.8	0.0	518.4	0.97	34	187.2	252.0	15.6	317.5	1.00
Papaya	34	6.6	32.8	0.0	190.0	0.12	34	13.5	65.0	0.0	380.0	0.27
Squash	0	–	–	–	–	–	0	–	–	–	–	–
Pumpkin	18	1.2	4.0	0.0	16.9	0.28	18	2.7	6.8	0.0	25.0	0.39
Banana	34	0.02	0.12	0.0	0.67	0.03	34	0.3	1.6	0.0	9.1	0.06
Watermelon	0	–	–	–	–	–	0	–	–	–	–	–
Arrowroot	34	3.9	12.0	0.0	631	0.1[illegible]	34	474	61.3	0.0	2 273	0.77
Citrus	34	0.0	0.0	0.0	0.0	0.0	34	0.0	0.0	0.0	0.0	0.0
Aqueous liquids	34	829.[illegible]	452.6	1[illegible].5	2751.2	1.00	34	530.0	399.2	0.0	2130.0	0.97
TOTAL	34	1185.2	517.9	431.6	3182.3	1.00	34	1431.7	672.9	525.0	2784.0	1.00

TABLE 19. Dietary intake in g/d for local food items in the Ujelang Survey for children from 0-3 years.

Food	Imports available: Number	Mean	σ	Low value	High value	Proportion of nonzeros	Imports unavailable: Number	Mean	σ	Low value	High value	Proportion of nonzeros
Fish	16	20.5	14.7	0.0	54.4	0.81	16	35.9	42.0	0.0	167.6	0.81
Shellfish	16	1.0	3.2	0.0	12.7	0.19	16	3.7	7.2	0.0	25.4	0.38
Clams	16	3.2	7.0	0.0	26.5	0.31	16	8.0	14.2	0.0	52.8	0.50
Crabs	16	2.0	3.8	0.0	13.0	0.38	16	3.9	6.5	0.0	25.9	0.63
Octopus	12	1.7	3.0	0.0	10.4	0.58	12	1.7	3.0	0.0	10.4	0.58
Turtle	12	0.7	1.7	0.0	6.1	0.50	12	0.9	1.8	0.0	6.1	0.58
Domestic meat	16	7.0	11.6	0.0	41.3	0.81	16	6.9	8.1	0.0	28.1	0.81
"il" b rds	16	1.6	3.2	0.0	9.6	0.25	16	10.2	11.6	0.0	38.2	0.63
Eggs	16	2.4	4.1	0.0	13.1	0.44	16	6.0	7.1	0.0	23.5	0.69
	16	10.2	19.1	0.0	56.0	0.63	16	22.2	24.8	0.0	56.0	0.81
Breadfruit	16	9.9	22.2	0.0	91.1	0.63	16	45.9	57.0	0.0	217.0	0.88
Coconut fluid	16	70.7	70.3	0.0	266.2	0.94	16	88.6	73.3	11.8	266.2	1.00
Coconut meat	16	38.4	83.1	0.0	322.2	0.81	16	111.5	177.3	0.0	721.2	0.81
Papaya	14	0.0	0.0	0.0	0.0	0.0	14	0.0	0.0	0.0	0.0	0.0
Squash	0	-	-	-	-	-	1	0.0	0.0	0.0	0.0	0.0
Pumpkin	8	0.04	0.11	0.0	0.31	0.13	8	0.3	0.7	0.0	1.9	0.25
Banana	15	0.02	0.09	0.0	0.34	0.07	15	0.02	0.09	0.0	0.34	0.07
Watermelon	0	-	-	-	-	-	0	-	-	-	-	-
Arrowroot	16	0.2	0.9	0.0	3.7	0.13	16	36.4	79.6	0.0	315.3	0.50
Citrus	15	0.0	0.0	0.0	0.0	0.0	15	0.0	0.0	0.0	0.0	0.0
Aqueous liquids	16	502.3	240.6	139.6	1065.0	1.00	16	282.1	124.6	50.9	532.5	1.00
TOTAL	16	671.2	275.2	139.6	1221.5	1.00	16	663.6	394.5	84.5	1576.9	1.00

TABLE 20. Dietary intake in g/d for local food items in the Ujelang Survey for children from 4-11 years.

Food	Imports available						Imports unavailable					
	Number	Mean	σ	Low value	High value	Proportion of nonzeros	Number	Mean	σ	Low value	High value	Proportion of nonzeros
Fish	37	29.6	19.4	0.0	[illegible]01.5	0.97	37	61.2	35.0	18.1	167.6	1.00
Shellfish	37	4.3	6.8	0.0	25.4	0.54	37	17.0	24.0	0.0	115.9	0.89
Clams	37	9.8	17.8	0.0	92.0	0.54	37	38.8	49.4	0.0	190.1	0.92
Crabs	37	2.2	4.3	0.0	13.0	0.49	37	12.3	21.2	0.0	90.5	0.89
Octopus	33	2.1	4.0	0.0	13.1	0.52	34	16.3	48.3	0.0	273.0	0.88
Turtle	35	1.5	2.9	0.0	10.6	0.63	35	3.2	4.3	0.0	13.2	0.94
Domestic meat	37	13.2	25.9	0.0	146.4	0.84	37	22.1	48.5	0.2	288.2	1.00
Wild birds	37	3.5	8.5	0.0	41.2	0.32	37	16.3	21.7	0.0	107.0	0.89
Eggs	37	5.5	15.9	0.0	91.0	0.49	37	18.2	46.1	0.0	273.0	0.95
Pandanus	37	5.2	9.8	0.0	56.0	0.62	37	23.3	21.5	0.0	84.0	1.00
Breadfruit	37	9.4	9.4	0.0	54.2	0.81	37	41.6	47.3	7.2	217.0	1.00
Coconut fluid	37	76.0	57.6	12.[illegible]	266.2	1.00	37	150.7	148.5	25.4	710.0	1.00
Coconut Meat	37	36.9	46.4	0.0	249.9	0.97	37	98.3	86.4	32.7	458.3	1.00
Papaya	34	5.6	17.4	0.0	95.0	0.21	34	8.4	18.5	0.0	76.0	0.35
Squash	0	-	-	-	-	-	0	-	-		-	-
Pumpkin	15	0.04	[illegible].16	0.0	0.62	[illegible].07	15	1.8	4.6	0.[illegible]	16.6	[illegible].27
Banana	37	0.0	[illegible]	0.0	0.0	[illegible]	37	0.0	0.0	[illegible]	0.0	0.[illegible]
Watermelon	0	-	-	-	-	-	0	-	-	-	-	-
Arrowroot	37	0.1	0.[illegible]	0.0	3.7	0.0	37	25.4	42.4	0.0	22.0	[illegible].7
Citrus	37	0.0	0.[illegible]	0.0	0.0	0.0	37	0.0	0.0	0.0	0.0	[illegible]
Aqueous liquids	37	536.3	226.[illegible]	83.4	1331.2	1.00	37	348.7	183.2	50.9	065.0	1.[illegible]
TOTAL	37	740.7	229.9	361.0	1539.8	1.00	37	900.6	406.1	397.0	2717.0	1.00

TABLE 21. Dietary intake in g/d for local food items in the Ujelang Survey for children from 12-17 years.

Food	Imports available: Number	Mean	σ	Low value	High value	Proportion of nonzeros	Imports unavailable: Number	Mean	σ	Low value	High value	Proportion of nonzeros
Fish	19	36.1	23.1	0.0	88.6	0.95	19	80.9	110.8	12.4	514.5	1.00
Shellfish	19	2.9	5.7	0.0	25.4	0.63	19	7.4	11.3	0.0	50.7	0.90
Clams	19	11.1	13.2	0.0	52.8	0.79	19	43.6	91.1	0.5	394.4	1.00
Crabs	19	3.7	6.5	0.0	25.9	0.47	19	30.1	62.5	0.0	271.5	0.90
Octopus	19	6.2	10.6	0.0	39.4	0.53	19	24.2	44.9	0.0	182.0	0.90
Turtle	18	2.8	6.2	0.0	26.4	0.56	18	5.4	12.2	0.0	52.8	0.89
Domestic meat	19	14.2	20.8	0.0	81.4	0.90	19	25.7	28.0	0.8	98.4	1.00
Wild birds	19	9.9	12.4	0.0	41.2	0.63	19	16.2	18.1	0.0	67.6	0.79
Eggs	19	10.4	13.0	0.0	39.2	0.68	19	27.8	42.8	0.0	182.0	0.84
Pandanus	19	6.7	11.7	0.0	48.2	0.68	19	22.0	23.3	4.0	96.3	1.00
Breadfruit	19	17.8	27.2	0.0	108.5	0.74	19	48.5	40.8	0.0	124.4	0.95
Coconut fluid	19	106.1	90.5	0.0	355.0	0.95	19	157.7	165.4	25.4	710.0	1.00
Coconut meat	19	54.2	71.6	1.9	307.7	1.00	19	133.0	109.9	43.7	471.2	1.00
Papaya	19	0.0	0.0	0.0	0.0	0.0	19	3.9	8.8	0.0	27.2	0.32
Squash	0	-	-	-	-	-	0	-	-	-	-	-
Pumpkin	11	4.1	8.7	0.0	25.5	0.27	11	7.0	12.1	0.0	33.2	0.45
Banana	19	0.0	0.0	0.0	0.0	0.0	19	0.0	0.0	0.0	0.0	0.0
Watermelon	0	-	-	-	-	-	0	-	-		-	-
Arrowroot	19	0.0	0.0	0.0	0.0	0.0	19	32.7	33.0	0.0	110.0	0.95
Citrus	19	0.0	0.0	0.0	0.0	0.0	19	0.0	0.0	0.0	0.0	0.0
Aqueous liquids	19	595.5	288.8	266.2	1 53.8	1.00	19	368.2	144.2	159.8	71[illegible]	1.00
TOTAL	19	879.7	359.9	456.9	1598.6	1.00	19	1031.0	482.4	439.4	2134.0	1.00

TABLE 22. Dietary intake in g/d for imported food items in the Ujelang Survey for adult males and females.

Food	Adult males						Adult females					
	Number	Mean	σ	Low value	High value	Proportion of nonzeros	Number	Mean	σ	Low value	High value	Proportion of nonzeros
Baked bread	36	31.8	33.4	1.5	180.0	1.00	34	30.3	33.5	3.2	180.0	1.00
Fried bread	36	62.8	67.9	6.7	372.0	1.00	34	72.0	55.6	6.7	186.0	1.00
Pancakes	36	48.0	38.9	0.0	166.0	0.97	34	59.5	49.9	6.0	166.0	1.00
Cake	36	2.4	6.4	0.0	30.3	0.56	34	2.6	3.2	0.0	10.1	0.85
Rice	36	240.6	123.5	36.9	514.5	1.00	34	233.5	130.6	36.9	686.0	1.00
Instant potatoes	36	67.7	102.8	0.0	355.0	0.72	32	126.8	133.0	0.0	443.8	0.94
Sugar	36	73.1	29.2	2.8	146.2	1.00	34	65.2	35.2	12.2	170.0	1.00
Canned meat and poultry	36	102.5	81.1	24.5	340.0	1.00	34	146.6	135.6	13.6	510.5	1.00
Canned fish	36	97.1	100.2	0.0	509.5	0.97	34	145.5	156.7	2.8	523.2	1.00
Other meat, fish, poultry	0	-	-	-	-	-	0	-	-	-	-	-
Carbonated drinks	36	360.7	224.3	509	1 065	1.00	34	337.9	206.4	50.9	10 650	1.00
Canned juices	36	197.8	263.9	0.0	1°65°	0.83	34	306.1	286.9	0.0	1065.0	0.91
Milk products	36	210.1	140.4	0.0	6 212	0.97	34	274.0	227.1	0.0	71 .0	0.97
Onion	1	0.0	0.0	0.0	0.0	0.0	2	0.0	0.0	0.0	0.0	0.0
Canned vegetables	1	0.0	0.0	0.0	0.0	0.0	0	-	-	-	-	-
Baby food	0	-	-	-	-	-	0	-	-	-	-	-
Cocoa	0	-	-	-	-	-	1	177.5	0.0	177.5	177.5	1.00
Ramen noodles	0	-	-	-	-	-		6.	0.0	6.1	6.	.00
Candy	0	-	-	-	-	-	0	-	-	-	-	-
TOTAL	36	1494.6	486.1	627.1	2720.5	1.00	34	1797.9	690.1	457.7	3136.5	1.00

TABLE 23. Dietary intake in g/d for imported food items in the Ujelang Survey for children from 0 to 3 years and from 4 to 11 years.

Food	Child: 0-3 years						Child: 4-11 years					
	Number	Mean	σ	Low value	High value	Proportion of nonzeros	Number	Mean	σ	Low value	High value	Proportion of nonzeros
Baked bread	16	10.5	11.1	0.8	45.0	1.00	37	21.1	16.8	2.2	67.5	1.00
Fried bread	16	26.2	30.7	0.0	93.3	0.81	37	43.4	29.0	6.7	93.0	1.00
Pancakes	16	25.2	30.9	0.0	83.3	0.81	37	38.4	27.7	4.8	83.0	1.00
Cake	16	1.5	2.9	0.0	10.1	0.56	37	1.2	2.4	0.0	10.1	0.51
Rice	16	97.0	89.8	0.0	343.0	0.88	36	153.7	84.2	24.6	343.0	1.00
Instant potatoes	14	49.0	37.4	0.0	88.8	0.93	37	80.3	92.0	0.0	355.0	0.87
Sugar	16	44.9	34.0	2.3	85.0	1.00	37	55.7	27.7	5.7	85.0	1.00
Canned meat and poultry	16	49.9	67.7	0.0	255.2	0.81	37	95.9	67.8	5.7	255.2	1.00
Canned fish	16	43.4	63.6	0.0	254.8	0.81	37	99.5	99.9	11.3	509.5	1.00
Other meat, fish, poultry	1	0.0	0.0	0.0	0.0	0.0	2	48.7	34.5	24.4	73.1	1.00
Carbonated drinks	16	171.3	118.5	0.0	355.0	0.88	37	226.5	120.7	50.9	532.5	1.00
Canned juices	16	84.5	106.1	0.0	355.0	0.81	37	157.8	149.9	0.0	532.5	0.92
Milk products	16	123.1	125.2	11.8	443.8	1.00	37	197.2	150.3	12.8	532.5	1.00
Onion	0	-	-	-	-	-	1	0.06	0.0	0.06	0.06	1.00
Canned vegetables	1	24.4	0.0	24.4	24.4	1.00	0	-	-	-	-	-
Baby food	1	68.2	0.0	68.2	68.2	1.00	0	-	-	-	-	-
Cocoa	0	-	-	-	-	-	1	0.0	0.0	0.0	0.0	0.0
Ramen noodles	0	-	-	-	-	-	0	-	-	-	-	-
Candy	1	0.5	0.0	0.5	0.5	1.00	1	0.5	0.0	0.5	0.5	1.0
TOTAL	16	726.3	320.4	203.3	1443.0	1.00	37	1174.1	417.8	374.0	2547.6	1.00

TABLE 24. Dietary intake in g/d for imported food items in the Ujelang Survey for children from 12 to 17 years.

Food	Number	Mean	σ	Low value	High value	Proportion of nonzeros
Baked bread	19	23.5	23.3	3.2	90.0	1.00
Fried bread	19	52.8	36.8	13.3	139.5	1.00
Pancakes	19	43.7	48.9	0.0	166.0	0.95
Cake	19	1.7	2.6	0.0	10.1	0.63
Rice	19	210.8	98.3	61.5	343.0	1.00
Instant potatoes	19	134.7	159.3	11.8	710.0	1.00
Sugar	19	67.6	27.5	5.7	85.0	1.00
Canned meat and poultry	19	123.5	84.8	24.5	364.4	1.00
Canned fish	19	124.9	114.5	24.4	509.5	1.00
Other meat, fish, poultry	0					
Carbonated drinks	19	286.3	101.2	25.4	355.0	1.00
Canned juices	19	220.2	259.0	0.0	1065.0	0.90
Milk products	19	247.6	166.2	0.0	532.5	0.90
Onion	1	0.0	0.0	0.0	0.0	0.0
Canned vegetables	0					
Baby food	0					
Cocoa	0					
Ramen noodles	1	6.1	0.0	6.1	6.1	1.0
Candy	0					
TOTAL	19	1537.6	478.5	1108.6	2720.9	1.00

Enewetak Atoll tends to fall in the B and C categories of the BNL report. We can, therefore, compare the results of the BNL study for categories B and C with the result from the Ujelang Dietary Survey which we used as the basis for the calculations in our report. The comparisons are listed in Table 25; the results under BNL are the range of results for the B and C categories.

In view of the fact the Ujelang Survey was conducted in an attempt to ascertain individual consumption and the BNL study was conducted to ascertain food prepared for a family, the results of the two surveys do for the most part reinforce each other;

TABLE 25. Diet comparisons for maximum diet from the Ujelang Survey and observations at Rongelap and Uterik.

	Adult female Ujelang Survey		BNL Marshall Island Diet Survey[a]
	Imports available	Imports unavailable	
Food	g/d	g/d	g/d
Fish	42	90	84-194
Shellfish[b]	5.1	25	0.14-0.4
Clams	8.9	44	5-15
Coconut crabs'	3.1	13	l-2
Domestic meat[d]	21	35	0.7-4.4
Wild birds	4 .	18	0.6-9
Eggs[e]	11	56	2.4
Pandanus	9	33	64-96
Breadfruit	27	93	36-53
Coconut fluid	142	217	430-521
Coconut meat	63	187	268-280
Squash (pumpkin)	0.2	0.7	o-5
Arrowroot	2.3	65	0
Papaya	7	14	o-12
Banana	0.02	0.3	17-19

[a]Work performed at Rongelap and Uterik by Dr. Jan Naidu of BNL. These are preliminary data and a final report.is in preparation.

[b]Marine crab and lobster.

'Includes land crabs.

[d]Pork and chicken.

[e]Bird, chicken, and turtle.

especially when the BNL survey admittedly probably overestimated the actual food consumed.

The largest discrepancy appears to be in the intake of coconut fluid--the range in the Ujelang survey was 142-217 g/d for the average intake and that from the BNL survey was 430-521 g/d. The coconut meat and Pandanus fruit intake in the BNL survey is 40-50% higher.

Fish consumption in the Ujelang survey is within the range observed by BNL. Intake of shellfish, clams, coconut crabs, domestic meat, wild birds, breadfruit, and arrowroot is greater in the Ujelang survey than the BNL survey. The intake of squash and papaya is very similar in the two reports' findings.

In evaluating all available data on dietary habits in the Marshall Islands there are a few general conclusions to be drawn:

1. The dietary intake used in our report is consistent with other published observations.

2. The dietary habits of a people are atoll-specific and one should not arbitrarily generalize from one atoll to another.

3. There is still some uncertainty as to what an "average diet" really is at any atoll.

4. Many factors can affect the average diet over any specific year.

5. Further atoll-specific dietary studies are needed to improve the precision of the dose assessments.

The "LLNL" diet used in previous assessments[1,8] was developed from observations[15] and published reports in the literature.[16] Because there were no direct surveys of the people in recent years the LLNL diet was designed to be conservative, i.e., overestimate the intake if anything. From the recent Ujelang and BNL surveys it appears that that was indeed the case in that all intake from the current surveys is less than that previously used.

LIVING PATTERNS

Doses have been estimated for three major living patterns at Enewetak Atoll. Each living pattern has also been evaluated for options on the source of some local foods and for time distributions. The living patterns are:

1. The Enjebi (Janet) Island living pattern with three variations:

a. Enjebi (Janet) Island as the residence island with 100% of the time spent on the island and all local foods from Enjebi (Janet). We assume that for the first 8 y after return, the coconut, breadfruit, and Pandanus fruit will come from the southern islands. After 8 y the trees, which would be planted on Enjebi (Janet) Island at the time of return, should be bearing fruit.

b. Enjebi (Janet) Island as the residence island with 15% of a person's time spent on other northern islands, Mijikadrek (Kate) through Billae (Wilma). Fifteen percent of the coconut intake is assumed to come from these other northern islands, otherwise all consumption is again from food crops on Enjebi (Janet) Island. The same situation for tree fruits applies for the first 8 y.

c. Enjebi (Janet) Island as the residence island with all coconut from the southern islands, Jinedrol (Alvin) through Kidrenen (Keith), and 15% of a person's time spent on the southern islands. The rest of the local food consumption would be from Enjebi (Janet) Island with the same situation for the first 8 y.

The Enjebi (Janet) Island living pattern results in the highest predicted doses for the living patterns evaluated in this report.

2. <u>The southern islands living pattern with two variations:</u>

a. Three southern islands—Japtan (David), Medren (Elmer), and Enewetak (Fred)—as the residence islands with 100% of a person's time spent on the southern islands, Jinedrol (Alivin) through Kidrenen (Keith), and all local foods from these islands.

b. Three southern islands—Japtan (David), Medren (Elmer), and Enewetak (Fred)—as the residence islands with 15% of the coconut intake from the northern islands, Mijikadrek (Kate) through Billae (Wilma), and 15% of a person's time spent on northern islands.

The southern island living pattern results in the lowest predicted doses for the living patterns evaluated in this report.

3. <u>The Aomon (Sally) and Bijire (Tilda) living pattern with two variations:</u>

a. Aomon (Sally) and Bijire (Tilda) as the residence islands with 100% of a person's time spent on these islands and all local foods from these islands. Coconut, breadfruit, and <u>Pandanus</u> fruit will come from the southern islands in the first 8 y.

b. Aomon (Sally) and Bijire (Tilda) as the residence islands with 15% of a person's time spent on the other northern islands and 15% percent of the coconut intake coming from other northern islands, Mijikadrek (Kate) through Billae (Wilma). The rest of the local foods would come from Aomon (Sally)/ Bijire (Tilda) with the usual exception in the first 8 y.

All doses for these living patterns are calculated assuming that radiological decay is the only mechanism resulting in reduced radionuclide concentrations with time.

The doses projected for these living patterns are based on the adult female diet, which represents the maximum adult intake resulting from the Ujelang Diet Survey.

The doses are also estimated for 2 cases from birth through 70 y for Enjebi (Janet) Island only. In the first scenario, the individual is born within the first year of return to Enjebi (Janet) and resides there continuously for 70 y. With four exceptions, all local foods consumed during a lifetime are assumed to come from Enjebi (Janet) only. Exceptions are the <u>Pandanus</u> fruit, breadfruit, coconut meat, and coconut fluid. For the first 8 y they are assumed to come from the southern islands. Thereafter, they too come from Enjebi (Janet) only.

In the second scenario, the individual is born 8 y after return to Enjebi (Janet), and also resides there continuously for the next 70 y. All local foods consumed during that lifetime are assumed to originate from Enjebi (Janet) only. This is consistent and in keeping with our first scenario in which southern-island sources of Pandanus fruit, breadfruit, coconut meat, and coconut fluid were terminated at the end of the eighth year.

Summarized in Table 26 are the dietary sources and corresponding radionuclide concentration decay periods assumed in estimating the ingestion doses from the two scenarios:

1. Ingestion dose from birth to the fourth year of life is based on the dietary intake of an average child in the range 0 through 3 y. In the first scenario, there is no decay correction applied to the radionuclide concentrations at the time the diet begins. However, in the second scenario, an 8-y decay correction is applied to account for the 8-y delay between the parent's return to Enjebi (Janet) and the individual's birth.

2. For the fourth to the twelfth years of life, ingestion dose is based on the dietary intake of an average child in the range 4 through 11 y. For the first scenario, two decay-period corrections are applied to the radionuclide concentrations. The first occurs at 4 y and is the point at which the diet for ages 4 through 11 commences. The second occurs at 8 y and is the point at which all subsistence foods begin to originate from Enjebi (Janet) only. With the second scenario, a single decay-period correction is applied at 12 y after return (4 y since birth); the point at which the diet for ages 4 through 12 commences.

3. Ingestion dose for the twelfth through seventeenth years of life is based on the dietary intake of an average child in the range 12 through 17 y. Decay-period corrections applied for this change in diet reflect commencement of the diet for the range 12 through 17 y; corrections are applied at 12 y for the first scenario and at 20 y (12 y since birth) for the second scenario.

4. For adulthood, the eighteenth through seventieth years of life, we have assumed (for the purpose of calculation) that the dose is that expected from the dietary intake of adult females. Decay-period corrections for commencement of the adult female diet are 18 y for the first scenario and 26 y (18 y since birth) for the second.

Inhalation and external doses estimated for each scenario reflect the previous assumption of continuous residence on Enjebi (Janet). In the first scenario, inhalation and external source contributions commence with the first year of return to Enjebi (Janet). With the second scenario, a decay-period correction of 8 y is applied to the inhalation and external sources before the dose estimates are made.

TABLE 26. Summary of dietary sources and corresponding radionuclide concentration decay periods assumed in estimating the ingestion dose to an individual from birth through 70 years of age.

	First scenario		Second scenario	
	Birth within first year		Birth at close of eighth year	
Ingestion period	Dietary source	Decay period	Dietary source	Decay period
Birth to fourth year	Child 0-3 years normal and famine	None	Child 0-3 years normal and famine	8 years
Fourth to twelfth year	Child 4-11 years normal and famine	4 years	Child 4-11 years normal and famine	12 years
	Child 4-11 years normal and famine	8 years		
Twelfth to eighteenth year	Child 12-17 years normal and famine	12 years	Child 12-17 years normal and famine	20 years
Adulthood	Adult females normal and famine	18 years	Adult females normal and famine	26 years

The predicted doses for each of the above living patterns and options are calculated for imported foods being both available and unavailable.

DOSE CALCULATIONS

BODY AND ORGAN WEIGHTS

Data from the Brookhaven National Laboratory[17,18] have been summarized to determine the body weight of the Marshallese people. The average body weights of the adult males and females are listed in Table 27. The average adult male body weight is 72 kg for Bikini, 71 kg for Enewetak, 62 kg for Rongelap, and 70 kg for Uterik; this is very near the 70-kg value of reference man.[5] As a result we have used 70 kg as the average body weight in our dose calculations. The lower body weight for Rongelap could be due to age distribution and health-related factors. The average body weight for 113 adult females in the Enewetak population is 61 kg; it is 67 kg for 30 Utirik females and 63 kg for 36 Rongelap females.[17]

STRONTIUM-90 METHODOLOGY

Bone-marrow doses and dose rates are calculated in two steps. First the model of Bennett[19-21] is used to correlate the ^{90}Sr concentrations in diet with that in mineral

TABLE 27. Body weights of Marshallese adult males in kg.

Atoll	Number	Mean	Std. deviation	Min.	Max.
Uterik[a]	9	69.0	12.9	59.5	92.7
Bikini[b]	18	71.9	12.4	50.0	100.5
Rongelap[a]	22	61.2[a]	9.2	46.4	86.8
TOTAL	49	66.6	6.4	46.4	100.5

[a] Twenty-Year Review of Medical Findings in a Marshallese Population Accidentally Exposed to Radioactive Fallout, Brookhaven National Laboratory, Upton, NY, BN-50424 (1975).

[b] H. Greenhouse, Brookhaven National Laboratory, Upton, NY, private communication (June, 1979).

bone. Next the dosimetric model developed by Spiers[22] is used to calculate the bone-marrow dose rate from the concentration in mineral bone.

Bennett's model is an empirical model developed from ^{90}Sr concentrations found in foods and autopsy bone samples from New York and San Francisco. The concentrations in the diet are the concentrations expected to result from worldwide fallout. The model is thought to adequately reflect the ^{90}Sr concentration in bone that corresponds to the ^{90}Sr concentration in the Marshallese diet; it uses as input the actual dietary ^{90}Sr concentration and the output is the actual ^{90}Sr concentration in mineral bone determined from analysis of autopsy samples. It also includes age-dependent variations which allow us to make dose estimates for children as well as adults. The calcium content of the normal diet for the Marshallese is listed in Table 28; the average intake is 0.7 g/d, which is very similar to the 0.9 g/d estimated for U.S. diets. The model is rather insensitive to calcium intake unless it greatly exceeds 1.0 g/d or is less than 0.3 g/d.[23] Therefore, the similar nature and the similar intake of Ca for the overall Marshallese diet relative to U.S. diets would indicate no major problems in applying the ^{90}Sr model to the Marshallese population.

Using Spiers model we calculate the dose rate, D_0, to a small, tissue-filled cavity in bone from the ^{90}Sr concentration in mineral bone. Then, from geometrical considerations, the dose rates to the bone marrow, D_m, and to endosteal cells, Ds, are calculated, using conversion factors $D_m/D_0 = 0.315$ and $D_s/D_0 = 0.434$, respectively. The conversion factors are those quoted in UNSCEAR[24] and are equivalent to a marrow dose rate of 1.4 mrad/y per pCi/g Ca and an endosteal cell dose rate of 1.9 mrad/y per pCi/g Ca. These dose rates are determined directly and not by comparison to radium so that rads are equivalent to rems. Since bone marrow is considered a blood-forming organ (annual dose limit equals 500 mrem/y) and endosteal cells are in the "other organ" category (annual dose limit equals 1500 mrem/y), the bone marrow is the more sensitive organ in bone for ^{90}Sr.[25]

CESIUM-137 AND COBALT-60 METHODOLOGY

For ^{137}Cs and ^{60}Co, the methods of ICRP[7,26,27] and NCRP[28] as developed by Killough and Rohwer in their "INDOS" code[29] are used for the dose calculations. This code is used as published; however, the output is modified to show the body burdens for each year. For ^{137}Cs, which is of major importance in the Marshall Islands, the model consists of 2 compartments with removal half-times of 2 and 110 d, with 10% of the intake going to the 2-d compartment and 90% to the 110-d compartment. These data are consistent with preliminary data obtained by Brookhaven National

TABLE 28. Average daily calcium intake for the Marshallese female diet for normal conditions.

Food	mg Ca per 100 g[a]	Intake, g/d	Ca (mg/d)
Fish	20	187	37
Meat	12	168	20
Breadfruit	22	27	5.9
Pandanus	10	9.2	0.92
Banana	7	0.02	0.001
Lobster	45	5.1	2.3
Milk	120	274	328
Coconut meat	10	63	63
Coconut fluid	30	142	43
Bread	23	102	23
Rice	10	234	23
Carbonated drink	8[b]	338	27
Canned juices	8[b]	306	25
Clams	100	8.9	8.9
Crabs	45	3.1	1.4
Potatoes	10	127	13
Eggs	55	11	6.1
Pancakes	215	60	129
TOTAL	700 mg/day		

[a] J.R.C. Buchanan, A Guide to Pacific Island Dietaries, South Pacific Board of Health, Sava, Fiji (1947).

[b] J.A.T. Pennington, Dietary Nutrient Guide, Avi Publishing Co., Westport, Conn. (1976).

Laboratory[30] on the half-time of the long-term compartment in the Marshallese. The average results from 10 Marshallese males showed a mean of 114 d (range: 76 to 178 d) for the long-term compartment. For 21 females the mean value is 83 d (range: 63 to 126 d). The gut transfer coefficient for ^{137}Cs is 1.0.

The model for ^{60}Co is a three-compartment model with half-times of 6, 60, and 800 d with 60, 20, and 20% of the intake, respectively.[7]

TRANSURANIC RADIONUCLIDES METHODOLOGY

Inhalation

The inhalation model used for the various isotopes of plutonium and for ^{241}Am is that of the ICRP Task Group.[6,31] Parameters for the lung model are those of the ICRP[7]; the gut-to-blood transfer for plutonium isotopes is 1×10^{-4} and for ^{241}Am is 5×10^{-4}. Both ^{241}Am and Pu are assumed to be class W compounds.

Ingestion

For the ingestion pathway, the gut transfer coefficients are as stated previously: 1×10^{-4} for Pu and 5×10^{-4} for Am. The critical organs are bone and liver with 100-y biological half-lives for Pu and Am in bone and 40 y in liver. Forty-five percent of the Pu and Am transferred to blood is assumed to reach the bone and 45% is assumed to reach the liver. The remaining 10% is distributed among other organs.

RESULTS

In this section the predicted maximum annual dose rates and the 30- and 50-y integral doses for the different living patterns and options are presented; we assume for purposes of discussion that residence will begin in January 1981. The doses are calculated using the average dietary intake, the average radionuclide concentration, the average biological residence times and fractional depositions, and the average external dose rates. The maximum annual dose rate for the whole body is defined as the dose rate in that year after the Marshallese return when the sum of the whole-body ingestion dose from ^{137}Cs and the external gamma dose is a maximum; and for bone marrow, when the bone-marrow ingestion dose from ^{137}Cs and ^{90}Sr and the external gamma dose is a maximum. Because of the buildup of dose from ^{90}Sr from ingestion and the continuously decreasing dose after the first year for ^{137}Cs for both ingestion and external gamma, the bone-marrow maximum annual dose rate can occur in a different year than the whole-body maximum annual dose rate; therefore, the external dose that contributes to the maximum annual dose rate can be different for the two cases. Figure 3 is a graphical illustration of this point. The maximum annual doses are listed in Table 29 for bone marrow and whole body for both imports-available and imports-unavailable conditions; they are broken down into ingestion and external gamma contributions. The year at which the maximum dose rate occurs is also listed. It is emphasized that doses listed for the imports-unavailable conditions are calculated assuming continuous consumption of local foods over a lifetime without imports ever being available. This is

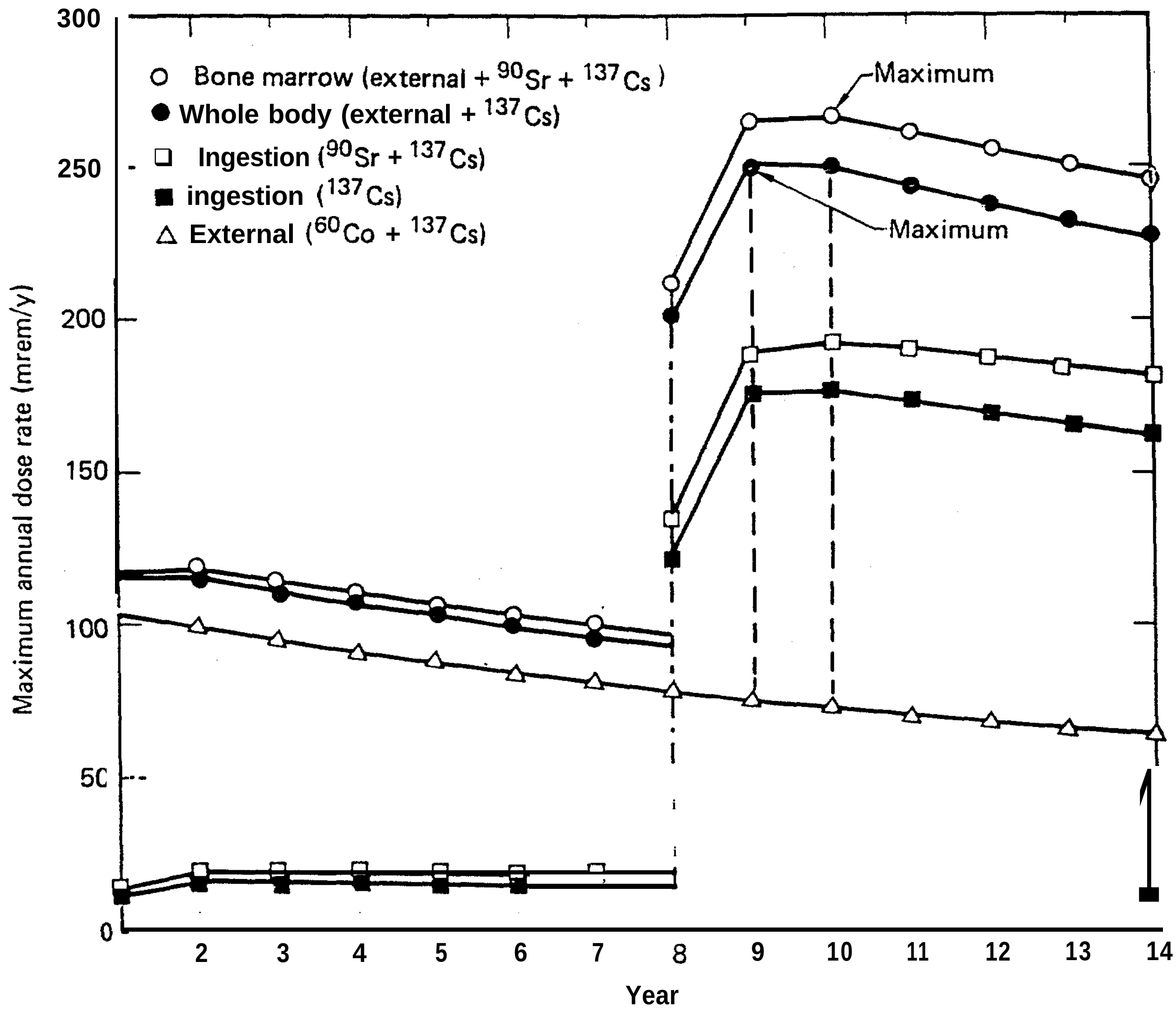

FIG. 3. Graphical representation of the maximum annual dose rates for whole body and bone marrow, and the corresponding external gamma dose that corresponds to the maximum year dose.

TABLE 29. Maximum annual dose rates in mrem/y for adult females for diet conditions when imports are available and unavailable.

Location	Type of diet	Organ	Pathway: Ingestion	Pathway: External gamma	Total	Year of maximum dose
Engebi (Janet)	Imports available	Bone marrow	237	54	291[a]	10
		Whole body	222	55	277[a]	9
	Imports unavailable	Bone marrow	500	54	554[a]	10
		Whole body	455	54	509[a]	10
Engebi (Janet) Northeast quadrant	Imports available	Bone marrow	231	55	286	10
		Whole body	215	57	272	9
	Imports unavailable	Bone marrow	489	55	544	10
		Whole body	440	55	495	10
Engebi (Janet) Southeast quadrant	Imports available	Bone marrow	176	51	227	10
		Whole body	166	53	219	9
	Imports unavailable	Bone marrow	370	51	421	10
		Whole body	341	51	392	10
Engebi (Janet) Southwest quadrant	Imports available	Bone marrow	205	47	252	10
		Whole body	189	49	238	9
	Imports unavailable	Bone marrow	434	47	481	10
		Whole body	389	47	436	10
Engebi (Janet) Northwest quadrant	Imports available	Bone marrow	322	64	386	10
		Whole body	302	66	368	9
	Imports unavailable	Bone marrow	677	64	741	10
		Whole body	620	64	684	10
Aomon (Sally)	Imports available	Bone marrow	41	13	54	9
		Whole body	39	13	52	9

TABLE 29. (Continued.

Location	Type of diet	Organ	Pathway: Ingestion	Pathway: External gamma	Total	Year of maximum dose
	Imports unavailable	Bone marrow	89	12	101	10
		Whole body	81	12	93	9
Bijire (Tilda)	Imports available	Bone marrow	41	12	53	10
		Whole body	38	12	50	9
	Imports unavailable	Bone marrow	87	12	99	10
		Whole body	78	12	90	9
Southern islands	Imports available	Bone marrow	3.9	1.2	5.1	3
		Whole body	3.3	1.2	4.5	2
	Imports unavailable	Bone marrow	9.8	1.1	11	5
		Whole body	7.4	1.2	8.6	3
Engebi (Janet) Island/northern islands[a]	Imports available	Bone marrow	215	49	264	10
		Whole body	200	50	250	9
	Imports unavailable	Bone marrow	456	49	505	10
		Whole body	412	49	461	10
Engebi (Janet) Island/southern islands[b]	Imports available	Bone marrow	39	47	86	9
		Whole body	21	62	83	2
	Imports unavailable	Bone marrow	107	43	150	12
		Whole body	63	47	110	9
Aomon (Sally) Island/northern islands[a]	Imports available	Bone marrow	44	14	58	9
		Whole body	42	14	56	9
	Imports unavailable	Bone marrow	96	13	109	10
		Whole body	87	13	100	9

TABLE 29. (Continued.

Location	Type of diet	Organ	Pathway: Ingestion	Pathway: External gamma	Total	Year of maximum dose
Bijire (Tilda) Island/northern islands[b]	Imports available	Bone marrow	43	14	57	9
		Whole body	41	14	55	9
	Imports unavailable	Bone marrow	94	13	107	10
		Whole body	85	13	98	9
Southern islands/northern islands	Imports available	Bone marrow	12	3.8	16	9
		Whole body	11	3.8	15	9
	Imports unavailable	Bone marrow	25	3.8	29	9
		Whole body	22	3.8	26	9
Engebi (Janet) Birth through 70 y[c]	Imports available	Bone marrow	160	41	201	21
		Whole body	142	41	183	21
	Imports unavailable	Bone marrow	366	41	407	21
		Whole body	311	41	352	21
Engebi (Janet) Birth through 70 y[d]	Imports available	Bone marrow	113	58	171	21
		Whole body	92	58	150	21
	Imports unavailable	Bone marrow	303	33	336	21
		Whole body	257	33	290	21

[a]If the average coconut intake per day were assumed to be twice that observed in the Ujelang Diet Survey (see text), then the estimated maximum annual dose would be about 60% higher.

[b]Fifteen percent of the coconut intake is from the Northern Islands.

[c]It is assumed that the child is born at the time of return and lives his entire lifespan on Enjebi (Janet) Island.

[d]It is assumed that the child is born 8 years after return and lives his entire lifespan on Enjebi (Janet) Island.

not a reasonable dietary pattern but it is presented to show the maximum case that could occur. Imported foods are not expected to be unavailable for more than a month or two each year, based on current lifestyle and projected expectations of the Enewetak people.

In Table 29 are listed the results for Enjebi (Janet) Island, the living pattern of major concern to some of the Enewetak people. In this living pattern all food is assumed to come from Enjebi (Janet) Island except during the first 8 y, during which time the coconut meat and fluid, breadfruit, and Pandanus fruit are assumed to come from the southern islands. For normal conditions with imported foods available, the predicted maximum annual dose rates are 290 mrem for bone marrow and 277 mrem to the whole body. If people were to live continually without imports, the predicted maximum annual dose rates are 554 mrem and 509 mrem for bone marrow and whole body, respectively.

Comparison of the doses predicted for the four quadrants of Enjebi (Janet), shows that three quadrants are less than the island average (Table 29) and one, the northwest quadrant, exceeds the island average. The doses for the northwest quadrant are 386 mrem/y for bone marrow and 368 mrem/y for whole body when imports are available; when imported foods are unavailable, the doses are 741 mrem/y for bone marrow and 684 mrem/y for whole body.

The maximum annual dose rates predicted for living patterns Aomon (Sally) and Bijire (Tilda) (all foods from these islands except during the first 8 y) are listed in Table 29. When imports are available, the doses predicted for Aomon (Sally) are 54 mrem/y to bone marrow and 52 mrem/y to whole body; for Bijire (Tilda) the bone-marrow and whole-body doses are 53 mrem/y and 50 mrem/y, respectively. For imports unavailable, the bone-marrow and whole-body doses are 101 mrem/y and 93 mrem/y for Aomon (Sally) and 99 mrem/y and 90 mrem/y for Bijire (Tilda).

The dose rates for the southern island living pattern are also listed in Table 29. The maximum annual dose rates predicted for this living pattern are extremely low. For normal conditions the maximum annual bone-marrow dose rate is 5.1 mrem and the whole-body dose rate is 4.5 mrem. For continuous conditions with no imported foods the maximum annual dose rates for bone marrow and whole body are only 11 mrem and 8.6 mrem, respectively.

Table 29 includes the variations to the major living patterns. For example, the maximum annual doses are listed for Enjebi (Janet) Island when 15% of a person's time is spent on other northern islands—Mijikadrek (Kate) through Billae (Wilma)—and 15% of the dietary intake of coconut comes from these islands; the other 85% of the coconut intake and 85% of the time are of course on Enjebi (Janet). Under these conditions the bone-marrow dose is reduced from an exclusive Enjebi (Janet) dose of 290 mrem/y to 264 mrem/y for normal conditions; for imports unavailable the reduction is from 554 to 505 mrem. Similar reductions occur in the whole-body doses. For the Enjebi (Janet) Island living pattern, the net effect of options for spending time on other northeastern islands is to reduce the dose from those predicted for the living pattern restricted exclusively to Enjebi (Janet) Island.

The reduction of the predicted Enjebi (Janet) Island doses is of course more dramatic for a case where all of the dietary coconut comes from the southern islands—Jinedrol (Alvin) through Kidrenen (Keith). In this case it is assumed that 15% of a person's time would also be spent on the southern islands. The doses for this option for normal conditions, i.e., imports available, are 83 mrem/y for whole body and 86 mrem/y for bone marrow; for imports unavailable the doses are 150 mrem/y and 110 mrem/y for bone marrow and whole body. The data are listed in Table 29.

For the living patterns involving Aomon (Sally) and Bijire (Tilda), use of coconuts from other northern islands and time spent on other northern islands slightly increases the predicted doses over those involving Aomon (Sally) and Bijire (Tilda) alone.

The predicted doses, when 15% of the coconut dietary intake for the southern island pattern is assumed to come from the northern islands and 15% of a person's time is spent on northern islands, are increased above those predicted for southern islands only. For the combined southern island-northern island living pattern the whole-body and bone-marrow doses are 15 mrem/y and 16 mrem/y for normal conditions and 26 mrem/y and 29 mrem/y for the conditions when imports are unavailable.

In Table 29 are also listed the predicted doses for a special case where a child is born on Enjebi (Janet) Island at the time of the people's return and spends his entire life on that island. For normal conditions when imports are available, the whole-body dose is 180 mrem/y and the bone marrow dose is 195 mrem/y. For comparison, the adults' doses for normal conditions for Enjebi (Janet) Island (see Table 29) are 235 mrem/y for whole-body and 250 mrem/y for bone marrow. When imports are unavailable, the corresponding doses are 350 mrem/y and 405 mrem/y. The corresponding imports-unavailable condition doses for adults are 455 mrem/y and 500 mrem/y. The results for the children, assuming that the child is born 8 y after the people return is the final entry in Table 29; the doses for normal conditions are 150 mrem/y for whole body and 170 mrem/y for bone marrow, both of which are lower than the other scenario, where the child is born at the time of the people's return.

Results for the 30- and 50-y integral whole-body and bone-marrow doses for the living patterns and options under consideration are listed in Tables 30 through 44. The doses are broken down into the contributions from the ingestion, external gamma, and inhalation pathways. The 30- and 50-y integral doses for the lung and bone via the inhalation pathway are listed in Table 45.

TABLE 30. Thirty- and 50-year integral doses in rem for adult females when imported foods are both available and unavailable for the Engebi (Janet) Island living pattern.

Pathway nuclide	30-year integral dose, rem: Whole body, Imports available	30-year: Whole body, Imports unavailable	30-year: Bone marrow, Imports available	30-year: Bone marrow, Imports unavailable	50-year integral dose, rem: Whole body, Imports available	50-year: Whole body, Imports unavailable	50-year: Bone marrow, Imports available	50-year: Bone marrow, Imports unavailable
Ingestion								
^{137}Cs	4.3	8.7	4.3	8.7	6.5	13	6.5	13
^{90}Sr	–	–	0.38	1.2	–	–	0.59	1.9
$^{239+240}Pu$[a]	–	–	0.0033	0.014	–	–	0.0088	0.037
^{241}Am[a]	–	–	0.0046	0.018	–	–	0.013	0.050
$^{241}Pu(^{241}Am)$[a]	–	–	0.0021	0.0077	–	–	0.0078	0.029
External gamma								
$^{137}Cs + ^{60}Co$	1.4	1.4	1.4	1.4	1.9	1.9	1.9	1.9
Inhalation								
$^{239+240}Pu$[a]	–	–	0.23	0.23	–	–	0.61	0.61
^{241}Am[a]	–	–	0.099	0.098	–	–	0.26	0.26
$^{241}Pu(^{241}Am)$[a]	–	–	0.026	0.026	–	–	0.094	0.094
TOTAL	5.7[b]	1[illegible][b]	6.1[b]	11[b]	8.4	15	9	17

[a]Mineral bone dose rather than bone marrow; these doses are not included in the total.

[b]If the average coconut intake per day were assumed to be twice that observed in the Ujelang Diet Survey (see text), then the estimated dose would be about 60% higher.

TABLE 31. Thirty- and 50-year integral doses in rem for adult females when imported foods are both available and unavailable for the Northeast Quadrant of Engebi (Janet) Island living pattern.

Pathway nuclide	30-year integral dose, rem				50-year integral dose, rem			
	Whole body		Bone marrow		Whole body		Bone marrow	
	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable
Ingestion								
^{137}Cs	4.1	8.4	4.1	8.4	6.3	13	6.3	13
^{90}Sr	-	-	0.41	1.3	-	-	0.65	2.0
$^{239+240}Pu$ [a]	-	-	0.0032	0.014	-	-	0.0088	0.037
^{241}Am [a]	-	-	0.0046	0.018	-	-	0.013	0.05
$^{241}Pu(^{241}Am)$ [a]	-	-	0.0021	0.0077	-	-	0.0078	0.029
External gamma								
$^{137}Cs + ^{60}Co$	1.5	1.5	1.5	1.5	2.0	2.0	2.0	2.0
Inhalation								
$^{239+240}Pu$ [a]	-	-	0.24	0.24	-	-	0.64	0.64
^{241}Am [a]	-	-	0.11	0.11	-	-	0.28	0.28
$^{241}Pu(^{241}Am)$ [a]	-	-	0.028	0.028	-	-	0.10	0.10
TOTAL	5.6	9.9	6.0	11	8.3	15	9	17

[a] Mineral bone dose rather than bone marrow; these doses are not included in the total.

TABLE 32. Thirty- and 50-year integral doses in rem for adult females when imported foods are both available and unavailable for the Southeast Quadrant of Engebi (Janet) Island living pattern.

	30-year integral dose, rem				50-year integral dose, rem			
	Whole body		Bone marrow		Whole body		Bone marrow	
Pathway nuclide	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable
Ingestion								
^{137}Cs	3.2	6.5	3.2	6.5	4.9	9.9	4.9	9.9
^{90}Sr	-	-	0.24	0.75	-	-	0.38	1.2
$^{239+240}Pu$[a]	-	-	0.0031	0.013	-	-	0.0084	0.036
^{241}Am[a]	-	-	0.0043	0.018	-	-	0.012	0.048
$^{241}Pu(^{241}Am)$[a]	-	-	0.0019	0.0074	-	-	0.0073	0.028
External gamma								
$^{137}Cs + ^{60}Co$	1.4	1.4	1.4	1.4	1.9	1.9	1.9	1.9
Inhalation								
$^{239+240}Pu$[a]	-	-	0.23	0.23	-	-	0.62	0.62
^{241}Am[a]	-	-	0.10	0.10	-	-	0.27	0.27
$^{241}Pu(^{241}Am)$[a]	-	-	0.027	0.027	-	-	0.097	0.097
TOTAL	4.6	7.9	4.8	8.7	6.8	12	7.2	13

[a]Mineral bone dose rather than bone marrow; these doses are not included in the total.

TABLE 33. Thirty- and 50-year integral doses in rem for adult females when imported foods are both available and unavailable for the Southwest Quadrant of Engebi (Janet) Island living pattern.

	30-year integral dose, rem				50-year integral dose, rem			
	Whole body		Bone marrow		Whole body		Bone marrow	
Pathway nuclide	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable
Ingestion								
^{137}Cs	3.7	7.4	3.7	7.4	5.6	11	5.6	11
^{90}Sr	-	-	0.38	1.2	-	-	0.6	1.9
$^{239+240}Pu^{a}$	-	-	0.003	0.014	-	-	0.0091	0.037
$^{241}Am^{a}$	-	-	0.0048	0.019	-	-	0.014	0.052
$^{241}Pu(^{241}Am)^{a}$	-	-	0.0021	0.0077	-	-	0.0078	0.029
External gamma								
$^{137}Cs + ^{60}Co$	1.3	1.3	1.3	1.3	1.7	1.7	1.7	1.7
Inhalation								
$^{239+240}Pu^{a}$	-	-	0.2	0.2	-	-	0.53	0.53
$^{241}Am^{a}$	-	-	0.090	0.090	-	-	0.24	0.24
$^{241}Pu(^{241}Am)^{a}$	-	-	0.024	0.024	-	-	0.087	0.087
TOTAL	5.0	8.7	5.4	9.9	7.3	13	7.9	15

[a] Mineral bone dose rather than bone marrow; these doses are not included in the total.

TABLE 34. Thirty- and 50-year integral doses in rem for adult females when imported foods are both available and unavailable for the Northwest Quadrant of Engebi (Janet) Island living pattern.

	30-year integral dose, rem				50-year integral dose, rem			
	Whole body		Bone marrow		Whole body		Bone marrow	
Pathway nuclide	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable
Ingestion								
^{137}Cs	5.8	12.	5.8	12	8.9	18	8.9	18
^{90}Sr	-	-	0.48	1.5	-	-	0.77	2.4
$^{239+240}Pu^{a}$	-	-	0.0038	0.015	-	-	0.010	0.040
$^{241}Am^{a}$	-	-	0.0049	0.019	-	-	0.014	0.052
$^{241}Pu(^{241}Am)^{a}$	-	-	0.0022	0.0076	-	-	0.0082	0.029
External gamma								
$^{137}Cs + ^{60}Co$	1.7	1.7	1.7	1.7	2.3	2.3	2.3	2.3
Inhalation								
$^{239+240}Pu^{a}$	-	-	0.23	0.23	-	-	0.61	0.61
$^{241}Am^{a}$	-	-	0.083	0.083	-	-	0.22	0.22
$^{241}Pu(^{241}Am)^{a}$	-	-	0.022	0.022	-	-	0.079	0.079
TOTAL	7.5	14	8	15	11	20	12	23

[a] Mineral bone dose rather than bone marrow; these doses are not included in the total.

TABLE 35. Thirty- and 50-year integral doses in rem for adult females when imported foods are both available and unavailable for the Engebi (Janet) Island/northern island living pattern.

Pathway nuclide	30-year integral dose, rem				50-year integral dose, rem			
	Whole body		Bone marrow		Whole body		Bone marrow	
	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable
Ingestion								
^{137}Cs	3.9	7.9	3.9	7.9	5.9	12	5.9	12
^{90}Sr	-	-	0.37	1.2	-	-	0.58	1.8
$^{239+240}Pu$ [a]	-	-	0.0032	0.014	-	-	0.0088	0.037
^{241}Am [a]	-	-	0.0046	0.018	-	-	0.013	0.05
$^{241}Pu(^{241}Am)$ [a]	-	-	0.0021	0.0076	-	-	0.0078	0.029
External gamma								
$^{137}Cs + ^{60}Co$	1.3	1.3	1.3	1.3	1.8	1.8	1.8	1.8
Inhalation								
$^{239+240}Pu$ [a]	-	-	0.23	0.23	-	-	0.61	0.61
^{241}Am [a]	-	-	0.094	0.094	-	-	0.25	0.25
$^{241}Pu(^{241}Am)$ [a]	-	-	0.025	0.025	-	-	0.090	0.090
TOTAL	5.2	9.2	5.6	10	7.7	14	8.3	16

[a] Mineral bone dose rather than bone marrow; these doses are not included in the total.

TABLE 36. Thirty- and 50-year integral doses in rem for adult females when imported foods are both available and unavailable for the Engebi (Janet) Island/southern island living pattern.

	30-year integral dose, rem				50-year integral dose, rem			
	Whole body		Bone marrow		Whole body		Bone marrow	
Pathway nuclide	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable
Ingestion								
^{137}Cs	0.66	.4	0.66	1.4	0.94	2.0	0.94	2.°
^{90}Sr	–	–	0.32	1.1	–	–	0.50	1.6
$^{239+240}Pu$[a]	–	–	0.0030	0.013	–	–	0.0081	0.035
^{241}Am[a]	–	–	0.0040	0.017	–	–	0.011	0.045
$^{241}Pu(^{241}Am)$[a]	–	–	0.0018	0.0072	–	–	0.0069	0.027
External gamma								
$^{137}Cs + ^{60}Co$	1.2	1.2	1.2	1.2	1.7	1.7	1.7	1.7
Inhalation								
$^{239+240}Pu$[a]	–	–	0.20	0.20	–	–	0.52	0.52
^{241}Am[a]	–	–	0.083	0.083	–	–	0.22	0.22
$^{241}Pu(^{241}Am)$[a]	–	–	0.022	0.022	–	–	0.080	0.080
TOTAL	1.9	2.6	2.2	3.7	2.6	3.7	3.1	5.3

[a] Mineral bone dose rather than bone marrow; these doses are not included in the total.

TABLE 37. Thirty- and 50-year integral doses in rem for adult females when imported foods are both available and unavailable for the Aomon (Sally) Island living pattern.

Pathway nuclide	30-year integral dose, rem				50-year integral dose, rem			
	Whole body		Bone marrow		Whole body		Bone marrow	
	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable
Ingestion								
^{137}Cs	0.77	1.6	0.77	1.6	1.2	2.4	1.2	2.4
^{90}Sr	-	-	0.062	0.20	-	-	0.095	0.31
$^{239+240}Pu$[a]	-	-	0.003	0.13	-	-	0.0079	0.035
^{241}Am[a]	-	-	0.0038	0.017	-	-	0.010	0.045
$^{241}Pu(^{241}Am)$[a]	-	-	0.0018	0.0072	-	-	0.0068	0.027
External gamma								
^{137}Cs + ^{60}Co	0.32	0.32	0.32	0.32	0.43	0.43	0.43	0.43
Inhalation								
$^{239+240}Pu$[a]	-	-	0.11	0.11	-	-	0.3	0.3
^{241}Am[a]	-	-	0.045	0.045	-	-	0.12	0.12
$^{241}Pu(^{241}Am)$[a]	-	-	0.012	0.012	-	-	0.043	0.043
TOTAL	1.1	1.9	1.2	2.1	1.6	2.8	1.7	3.1

[a]Mineral bone dose rather than bone marrow; these doses are not included in the total.

TABLE 38. Thirty- and 50-year integral doses in rem for adult females when imported foods are both available and unavailable for the Aomon (Sally) Island/Northern Islands living pattern.

Pathway nuclide	30-year integral dose, rem: Whole body, Imports available	30-year: Whole body, Imports unavailable	30-year: Bone marrow, Imports available	30-year: Bone marrow, Imports unavailable	50-year integral dose, rem: Whole body, Imports available	50-year: Whole body, Imports unavailable	50-year: Bone marrow, Imports available	50-year: Bone marrow, Imports unavailable
Ingestion								
^{137}Cs	0.83	1.7	0.83	1.7	1.3	2.6	1.3	2.6
^{90}Sr	-	-	0.063	0.20	-	-	0.098	0.31
$^{239+240}Pu$[a]	-	-	0.003	0.13	-	-	0.0078	0.035
^{241}Am[a]	-	-	0.0039	0.017	-	-	0.010	0.045
$^{241}Pu(^{241}Am)$[a]	-	-	0.0018	0.0072	-	-	0.0068	0.027
External gamma								
$^{137}Cs + ^{60}Co$	0.35	0.35	0.35	0.35	0.47	0.47	0.47	0.47
Inhalation								
$^{239+240}Pu$[a]	-	-	0.10	0.10	-	-	0.27	0.27
^{241}Am[a]	-	-	0.049	0.049	-	-	0.13	0.13
$^{241}Pu(^{241}Am)$[a]	-	-	0.0013	0.0013	-	-	0.0048	0.0048
TOTAL	1.2	2.1	1.2	2.3	1.8	3.1	1.9	[illegible]4

[a] Mineral bone dose rather than bone marrow; these doses are not included in the total.

TABLE 39. Thirty- and 50-year integral doses in rem for adult females when imported foods are both available and unavailable for the Bijire (Tilda) Island living pattern.

Pathway nuclide	30-year integral dose, rem: Whole body, Imports available	Imports unavailable	Bone marrow, Imports available	Imports unavailable	50-year integral dose, rem: Whole body, Imports available	Imports unavailable	Bone marrow, Imports available	Imports unavailable
Ingestion								
^{137}Cs	0.75	1.5	0.75	1.5	1.1	2.3	1.1	2.3
^{90}Sr	-	-	0.064	0.21	-	-	0.099	0.32
$^{239+240}Pu$[a]	-	-	0.0029	0.013	-	-	0.0078	0.035
^{241}Am[a]	-	-	0.0038	0.017	-	-	0.0010	0.045
$^{241}Pu(^{241}Am)$[a]	-	-	0.0018	0.0072	-	-	0.0068	0.027
External gamma								
$^{137}Cs + {}^{60}Co$	0.32	0.32	0.32	0.32	0.43	0.43	0.43	0.43
Inhalation								
$^{239+240}Pu$[a]	-	-	0.061	0.061	-	-	0.16	0.16
^{241}Am[a]	-	-	0.037	0.037	-	-	0.1	0.1
$^{241}Pu(^{241}Am)$[a]	-	-	0.0099	0.0099	-	-	0.036	0.036
TOTAL	1.1	1.8	1.1	2.0	1.5	2.7	1.6	3.1

[a]Mineral bone dose rather than bone marrow; these doses are not included in the total.

TABLE 40. Thirty- and 50-year integral doses in rem for adult females when imported foods are both available and unavailable for the Bijire (Tilda) Island/Northern Islands living pattern.

Pathway	30-year integral dose, rem				50-year integral dose, rem			
	Whole body		Bone marrow		Whole body		Bone marrow	
nuclide	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable
Ingestion								
^{137}Cs	0.81	1.7	0.81	1.7	1.2	2.5	1.2	2.5
^{90}Sr	-	-	0.066	0.21	-	-	0.10	0.33
$^{239+240}Pu^{a}$	-	-	0.0029	0.013	-	-	0.0079	0.035
$^{241}Am^{a}$	-	-	0.0038	0.017	-	-	0.0010	0.045
$^{241}Pu(^{241}Am)^{a}$	-	-	0.0018	0.0072	-	-	0.0068	0.027
External gamma								
$^{137}Cs + ^{60}Co$	0.35	0.35	0.35	0.35	0.47	0.47	0.47	0.47
Inhalation								
$^{239+240}Pu^{a}$	-	-	0.10	0.10	-	-	0.27	0.27
$^{241}Am^{a}$	-	-	0.049	0.049	-	-	0.13	0.13
$^{241}Pu(^{241}Am)^{a}$	-	-	0.0013	0.0013	-	-	0.0048	0.0048
TOTAL	1.2	2.1	1.2	2.3	1.7	3	1.8	3.3

[a]Mineral bone dose rather than bone marrow; these doses are not included in the total.

TABLE 41. Thirty- and 50-year integral doses in rem for adult females when imported foods are both available and unavailable for the Southern Islands living pattern.

Pathway nuclide	30-year integral dose, rem: Whole body, Imports available	Whole body, Imports unavailable	Bone marrow, Imports available	Bone marrow, Imports unavailable	50-year integral dose, rem: Whole body, Imports available	Whole body, Imports unavailable	Bone marrow, Imports available	Bone marrow, Imports unavailable
Ingestion								
^{137}Cs	0.074	0.17	0.074	[illegible]	[illegible]	0.23	0.10	0.23
^{90}Sr	–	–	0.019	0.066	–	–	0.026	0.093
$^{239+240}Pu$[a]	–	–	0.0028	0.013	–	–	0.0076	0.035
^{241}Am[a]	–	–	0.0035	0.016	–	–	0.0094	0.043
$^{241}Pu(^{241}Am)$[a]	–	–	0.0016	0.0067	–	–	0.0059	0.025
External gamma								
$^{137}Cs + ^{60}Co$	0.025	0.025	0.025	0.025	0.033	0.033	0.033	0.033
Inhalation								
$^{239+240}Pu$[a]	–	–	0.0009	0.0009	–	–	0.0024	0.0024
^{241}Am[a]	–	–	0.00053	0.00053	–	–	0.0014	0.0014
$^{241}Pu(^{241}Am)$[a]	–	–	0.00014	0.00014	–	–	0.00051	0.00051
TOTAL	0.10	0.20	0.12	0.26	0.13	0.26	0.16	0.36

[a]Mineral bone dose rather than bone marrow; these doses are not included in the total.

TABLE 42. Thirty- and 50-year integral doses in rem for adult females when imported foods are both available and unavailable for the Southern Islands/Northern Islands living pattern.

Pathway nuclide	30-year integral dose, rem: Whole body, Imports available	30-year: Whole body, Imports unavailable	30-year: Bone marrow, Imports available	30-year: Bone marrow, Imports unavailable	50-year integral dose, rem: Whole body, Imports available	50-year: Whole body, Imports unavailable	50-year: Bone marrow, Imports available	50-year: Bone marrow, Imports unavailable
Ingestion								
^{137}Cs	0.22	0.46	0.22	0.46	0.33	0.68	0.33	0.68
^{90}Sr	-	-	0.021	0.071	-	-	0.030	0.10
$^{239+240}Pu$[a]	-	-	0.0029	0.013	-	-	0.0076	0.035
^{241}Am[a]	-	-	0.0036	0.016	-	-	0.0096	0.044
$^{241}Pu(^{241}Am)$[a]	-	-	0.0016	0.0067	-	-	0.0060	0.025
External gamma								
$^{137}Cs + ^{60}Co$	0.098	0.098	0.098	0.098	0.13	0.13	0.13	0.13
Inhalation								
$^{239+240}Pu$[a]	-	-	0.035	0.035	-	-	0.094	0.094
^{241}Am[a]	-	-	0.013	0.013	-	-	0.034	0.034
$^{241}Pu(^{241}Am)$[a]	-	-	0.0034	0.0034	-	-	0.012	0.012
TOTAL	0.32	0.56	0.34	0.63	0.46	0.81	0.49	0.91

[a]Mineral bone dose rather than bone marrow; these doses are not included in the total.

TABLE 43. Thirty- and 50-year integral doses in rem for a child[a] when imported foods are both available and unavailable for the Enjebi (Janet) Island living pattern.

Pathway nuclide	30-year integral dose, rem: Whole body, Imports available	30-year: Whole body, Imports unavailable	30-year: Bone marrow, Imports available	30-year: Bone marrow, Imports unavailable	50-year integral dose, rem: Whole body, Imports available	50-year: Whole body, Imports unavailable	50-year: Bone marrow, Imports available	50-year: Bone marrow, Imports unavailable
Ingestion								
^{137}Cs	3.8	7.5	3.8	7.5	6.1	12	6.1	12
^{90}Sr	-	-	0.36	1.1	-	-	0.58	1.8
$^{239+240}Pu$[b]	-	-	0.0032	0.012	-	-	0.0094	0.036
^{241}Am[b]	-	-	0.0045	0.015	-	-	0.014	0.047
$^{241}Pu(^{241}Am)$[b]	-	-	0.0017	0.0059	-	-	0.0072	0.024
External gamma								
$^{137}Cs + ^{60}Co$	1.4	1.4	1.4	1.4	1.9	1.9	1.9	1.9
Inhalation[c]								
$^{239+240}Pu$[b]	-	-	0.23-	0.23	-	-	0.61	0.61
^{241}Am[b]	-	-	0.099	0.099	-	-	0.26	0.26
$^{241}Pu(^{241}Am)$[b]	-	-	0.026	0.026	-	-	0.094	0.094
TOTAL	5.2	[illegible]	5.6	10	8	14	8.6	16

[a]It is assumed that the child is born at the time of return and lives his entire life on Enjebi Island.

[b]Mineral bone dose rather than bone marrow; these doses are not included in the total.

[c]The inhalation dose for children is assumed to be the same as the adult.

TABLE 44. Thirty- and 50-year integral doses in rem for a child[a] when imported foods are both available and unavailable for the Engebi (Janet) Island living pattern.

Pathway nuclide	30-year integral dose, rem				50-year integral dose, rem			
	Whole body		Bone marrow		Whole body		Bone marrow	
	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable	Imports available	Imports unavailable
Ingestion								
^{137}Cs	4.0	8.1	4.0	8.1	6	12	6	12
^{90}Sr	-	-	0.42	1.3	-	-	0.61	1.9
$^{239+240}Pu$ [b]	-	-	0.0034	0.012	-	-	0.0096	0.036
^{241}Am [b]	-	-	0.0049	0.016	-	-	0.014	0.048
$^{241}Pu(^{241}Am)$ [b]	-	-	0.0018	0.0059	-	-	0.0072	0.024
External gamma								
$^{137}Cs + ^{60}Co$	1.1	1.1	1.1	1.1	1.5	1.5	1.5	1.5
Inhalation[c]								
$^{239+240}Pu$ [b]	-	-	0.23	0.23	-	-	0.61	0.61
^{241}Am [b]	-	-	0.099	0.099	-	-	0.2	0.26
$^{241}Pu(^{241}Am)$ [b]	-	-	0.026	0.026	-	-	0.0 4	0.094
TOTAL	5.1	9.2	5.5	10.5	7.5	13.5	8.1	15

[a] It is assumed that the child is born 8 years after return and lives his entire lifespan on Enjebi Island.

[b] Mineral bone dose rather than bone marrow; these doses are not included in the total.

[c] The inhalation dose for children is assumed to be the same as the adult.

TABLE 45. Thirty- and 50-year integral bone and lung doses in rem via the inhalation pathway for 4 living patterns at Enewetak Atoll.

Living pattern	Isotope	Lung		Bone	
		30-year	50-year	30-year	50-year
Enjebi (Janet)	$^{239+240}Pu$	0.056	0.095	0.23	0.61
	^{241}Am	0.025	0.042	0.1	0.26
	$^{241}Pu(^{241}Am)$	0.0087	0.019	0.026	0.094
Aomon (Sally)	$^{239+240}Pu$	0.028	0.047	0.11	0.3
	^{241}Am	0.012	0.019	0.045	0.12
	$^{241}Pu(^{241}Am)$	0.004	0.0086	0.012	0.043
Bijire (Tilda)	$^{239+240}Pu$	0.015	0.026	0.061	0.16
	^{241}Am	0.0096	0.016	0.037	0.1
	$^{241}Pu(^{241}Am)$	0.0034	0.0072	0.0099	0.036
Southern Islands	$^{239+240}Pu$	0.00023	0.00038	0.0009	0.0024
	^{241}Am	0.00014	0.00023	0.00053	0.0014
	$^{241}Pu(^{241}Am)$	0.000047	0.00010	0.00014	0.00051

The doses predicted for imports-available and imports-unavailable conditions on Enjebi (Janet) Island are listed in Table 30. For normal conditions, the 30-y integral whole-body dose is 5.7 rem and the bone-marrow dose is 6.1 rem. For imports unavailable, the doses are 10 rem and 11 rem, respectively. Tables 31-34 list the doses for the four quadrants of Enjebi (Janet) Island. For the case listed in Table 35 where the residence island is Enjebi (Janet) but 15% of the dietary coconut comes from other northern islands, the 30-y integral whole-body and bone-marrow doses for imports available drop to 5.2 rem and 5.6 rem. When Enjebi (Janet) is the residence island but all coconut comes from the southern islands, the data listed in Table 36 show that, with imports available (i.e., for normal conditions), the 30-y integral whole-body dose is 1.9 rem and the bone-marrow dose is 2.2 rem. For the imports-unavailable conditions, the corresponding doses are 2.6 and 3.1 rem. Tables 37-40 list the results for the Aomon (Sally) and Bijire (Tilda) living patterns; all doses are much less than those predicted for Enjebi (Janet) Island living patterns.

The 30-y doses predicted for the southern island living pattern for normal conditions are 0.10 rem for whole body and 0.12 rem for bone marrow (Table 41). For imports available the corresponding doses rise to 0.20 rem and 0.26 rem. The integral doses for the southern island/northern island option fall between the values given for the Enjebi (Janet) Island pattern and the southern island pattern and are listed in Table 42.

For the special calculation made for children born at the time of return to Enjebi (Janet) Island, the 30-y integral whole-body and bone-marrow doses for normal conditions are 4.2 rem and 4.7 rem, respectively (Table 43). For the adult case given in Table 30, the results were 4.9 rem and 5.5 rem. For imports unavailable, the 30-y integral doses for children are again less than those estimated for adults. The doses for the scenario where the child is born 8 y after return (Table 44) are less than when the child is born at the time of return.

DISTRIBUTION OF DOSES AROUND THE ESTIMATED AVERAGE DOSE

The doses presented in this paper and listed in Tables 29 through 44 are calculated using the mean value of the data available for each parameter in the dose models. For example, some of the model parameters are body weight, residence time of radionuclides in the body, radionuclide concentrations in either foods or soil, dietary intake (measured in grams per day), and fractional deposition of radionuclides in body organs or compartments. Data for all of these parameters have a log-normal distribution. Thus the mean value calculated from the data does not represent the midpoint of the distribution but rather falls somewhere above the 50th percentile point in the distribution.

Figures 4 through 13 show the distributions for body weight, dietary intake, soil concentration, and ^{137}Cs whole-body residence time as examples; the mean value falls at the 68th percentile, that is, approximately 68% of the data points fall below the mean value. The important question raised by this observation is that if mean values are used in the dose models and the data sets are log-normally distributed, where do the final calculated "average dose" numbers fall on the distribution of final doses? This complex problem requires a computer analysis of the type of distribution and the associated variance for each parameter in the model to determine the distribution of estimated doses and the associated variance.

In our case, for the estimated doses at Enewetak Atoll, ^{137}Cs accounts for approximately 85% of the total dose. Therefore, focusing only on ^{137}Cs we have used a Monte Carlo method to determine the distribution in the final dose estimates. The impact on the final distribution of ignoring the ^{90}Sr component will be small. Adding

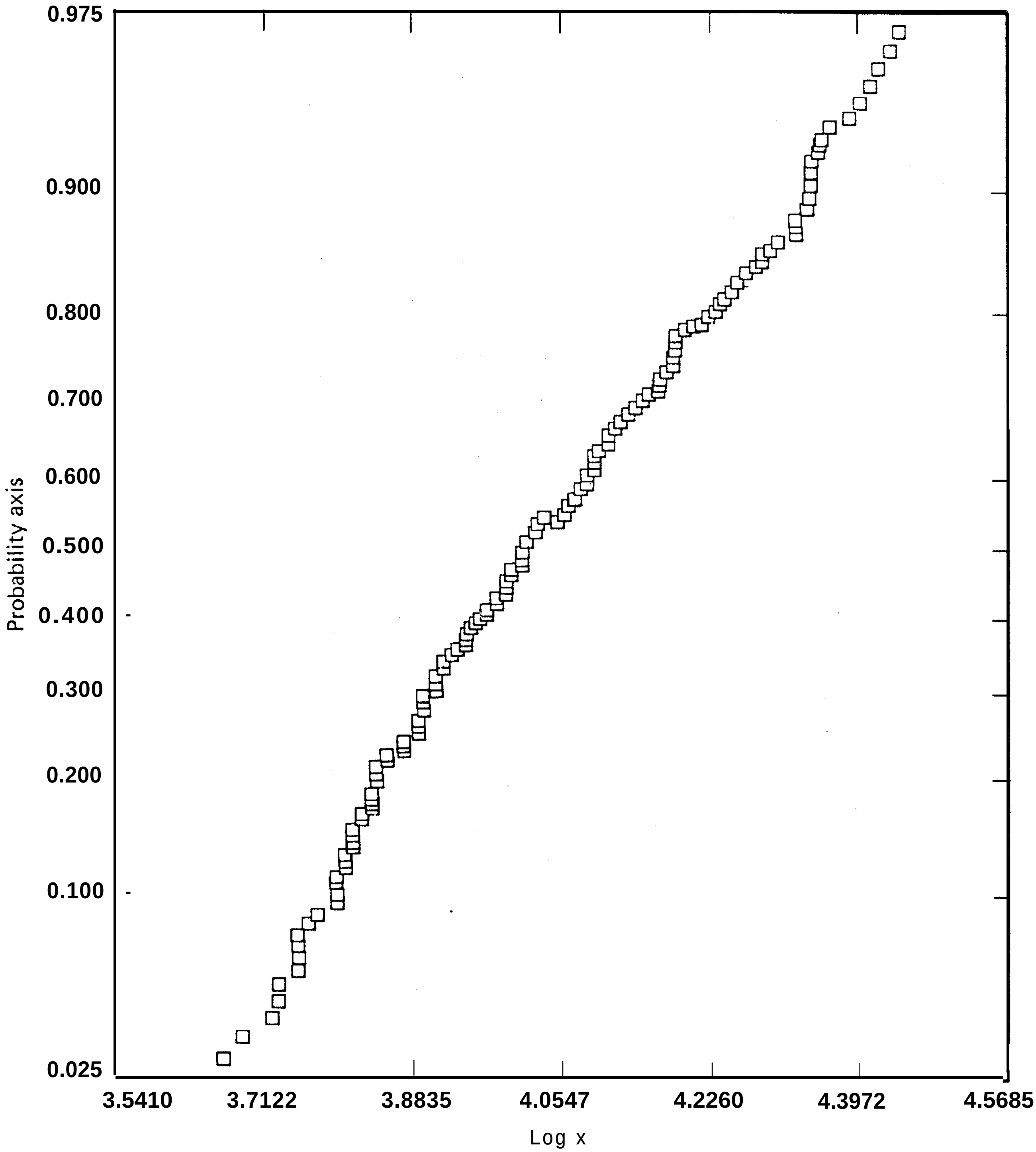

FIG. 4. Log probability plot for the body weight of 172 adult Marshallese females.

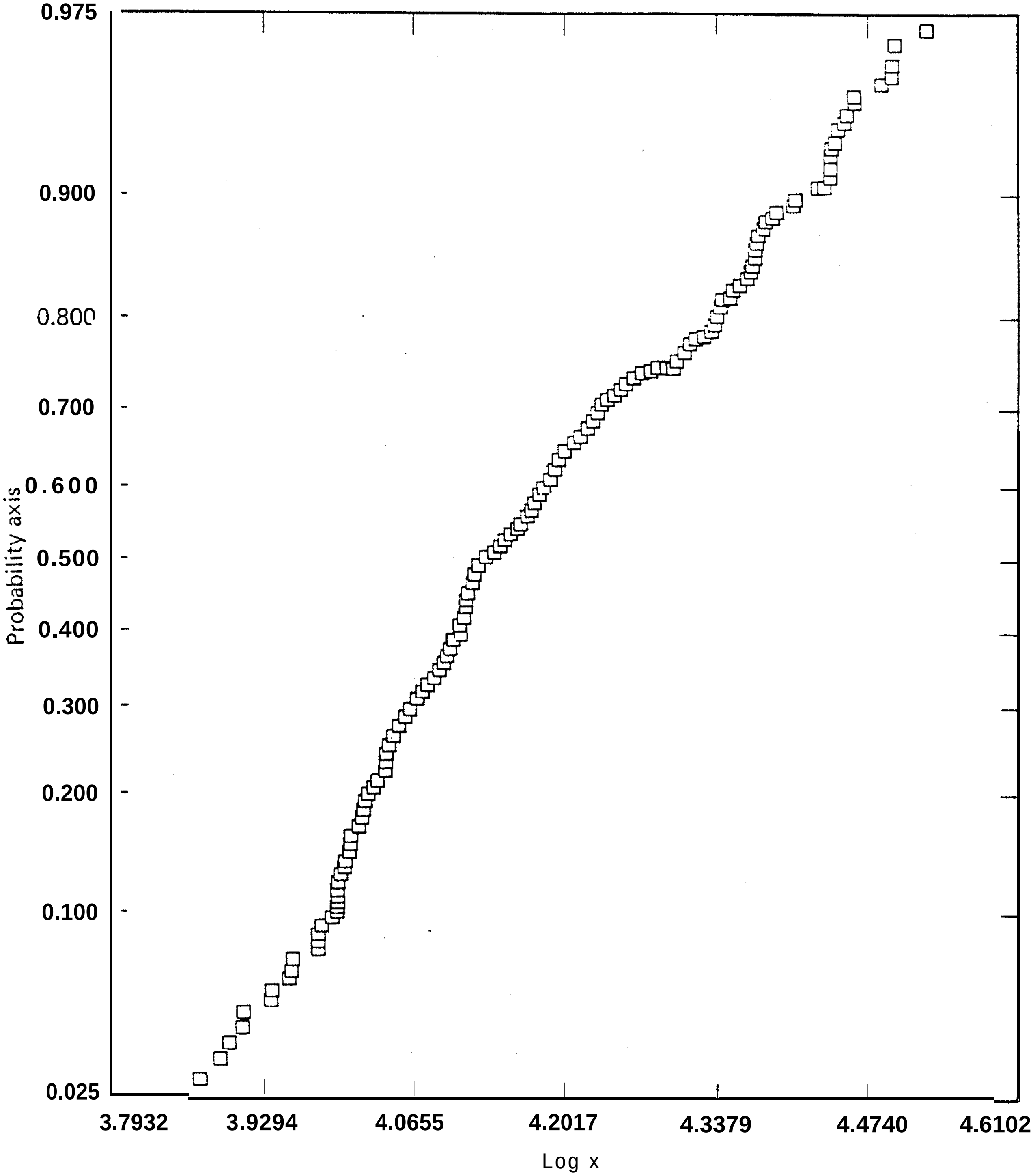

FIG. 5. Log probability plot for the body weight of 206 adult Marshallese males.

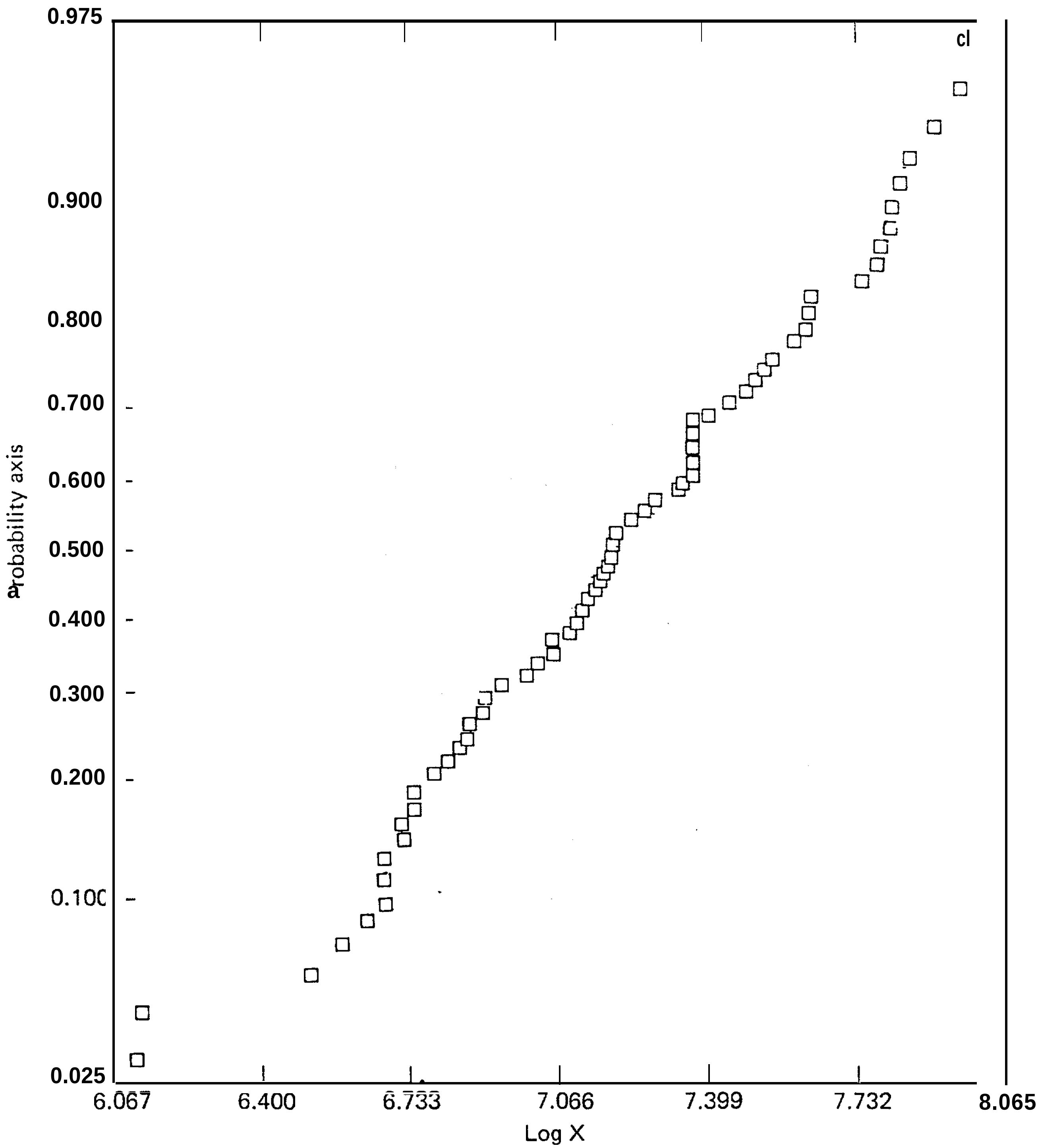

FIG. 6. Log probability plot of the dietary intake of 34 Marshallese females.

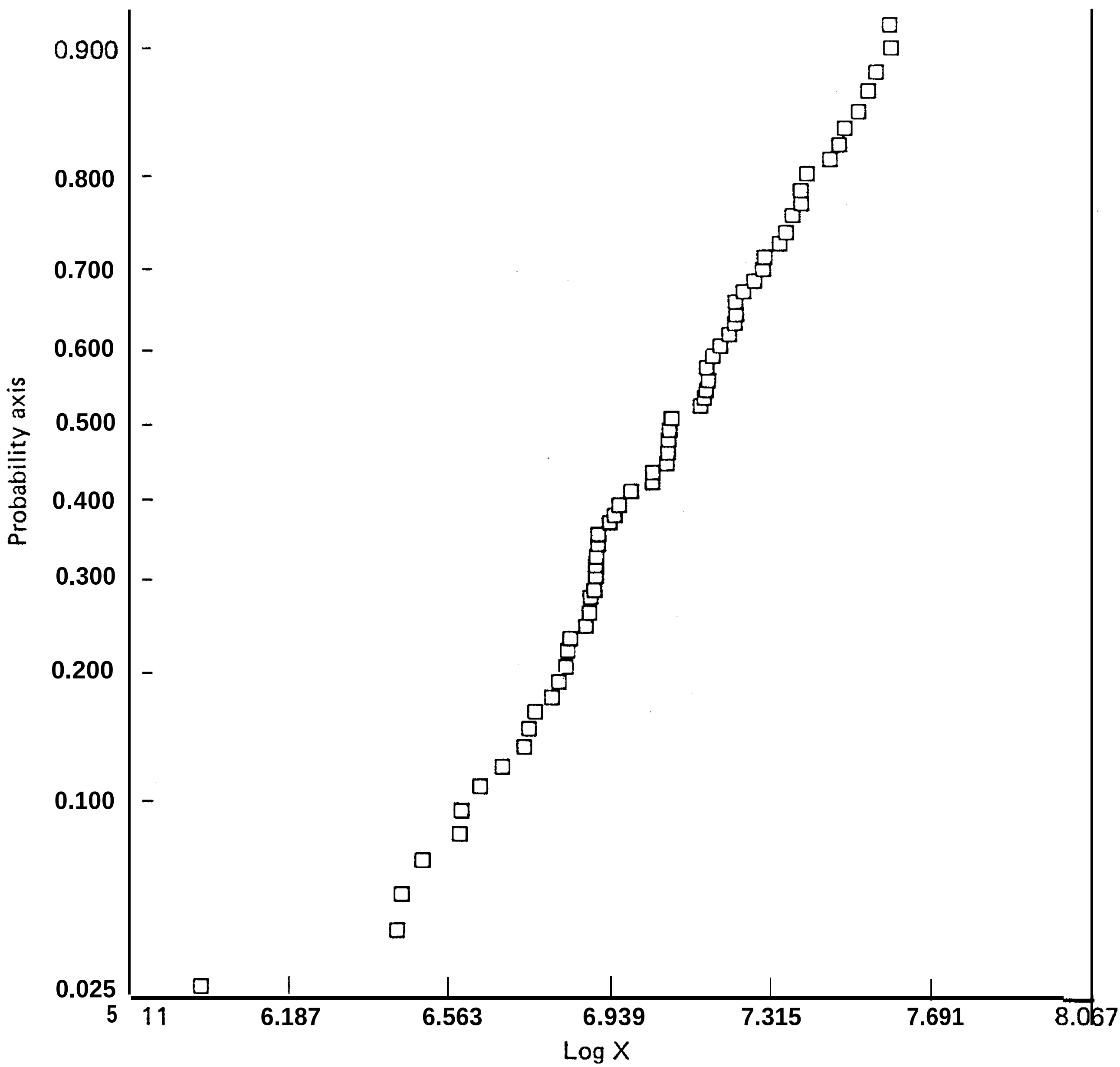

FIG. 7. Log probability plot of the dietary intake of 36 Marshallese males.

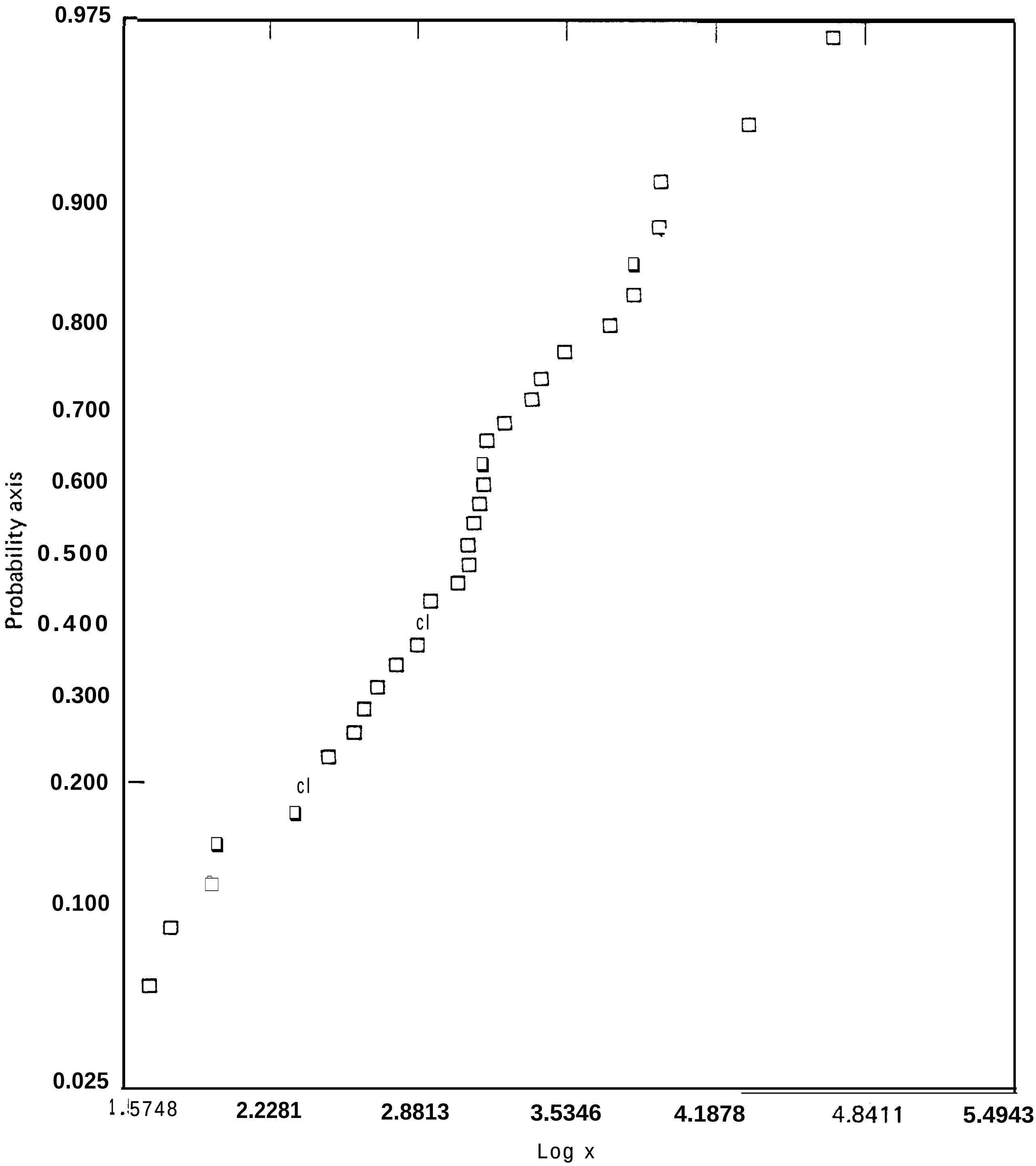

FIG. 8. Log probability plot of the ^{137}Cs concentration in coconut meat.

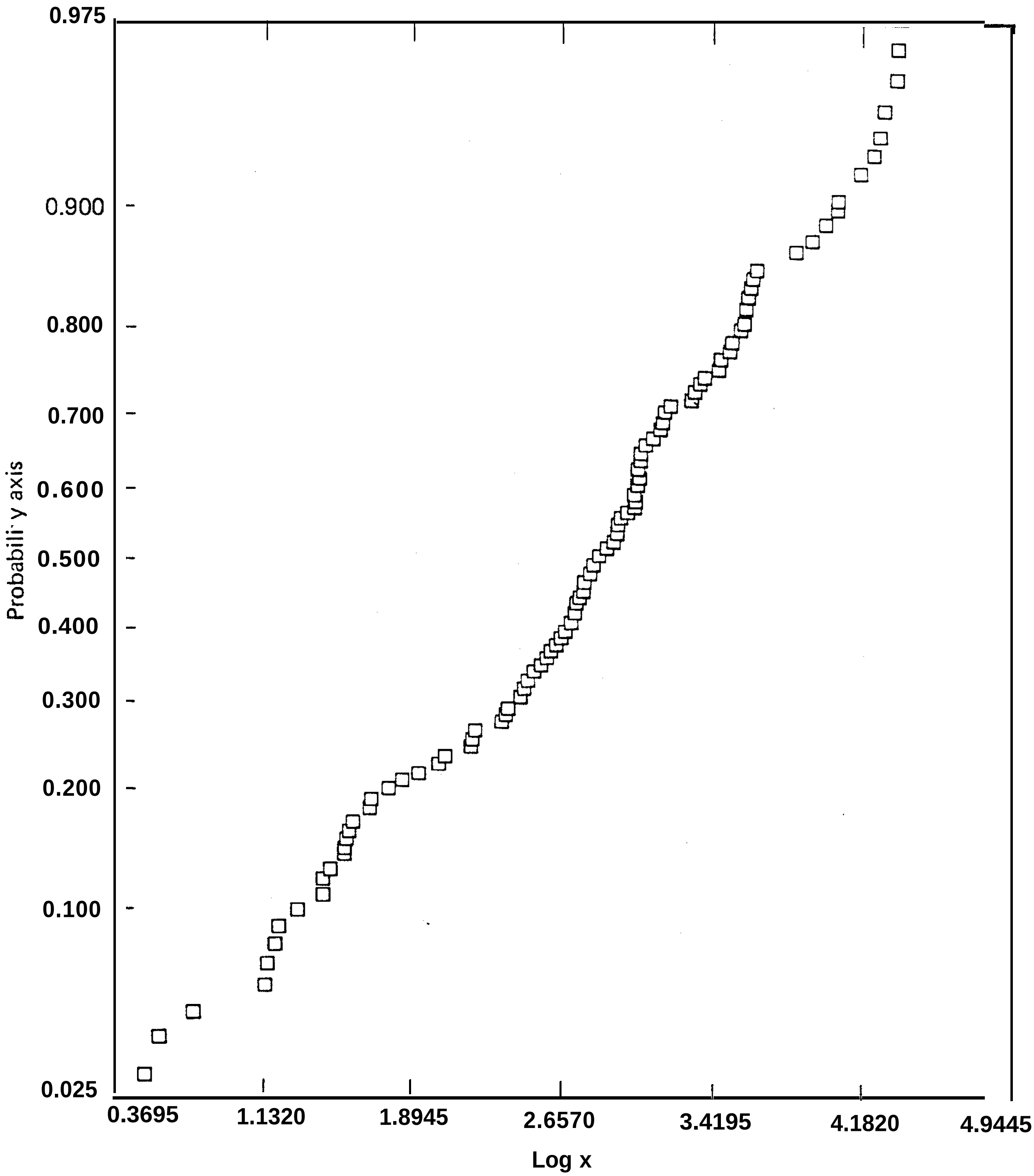

FIG. 9. Concentration of ^{137}Cs in the top 0-5 cm of soil at Enjebi (Janet) Island.

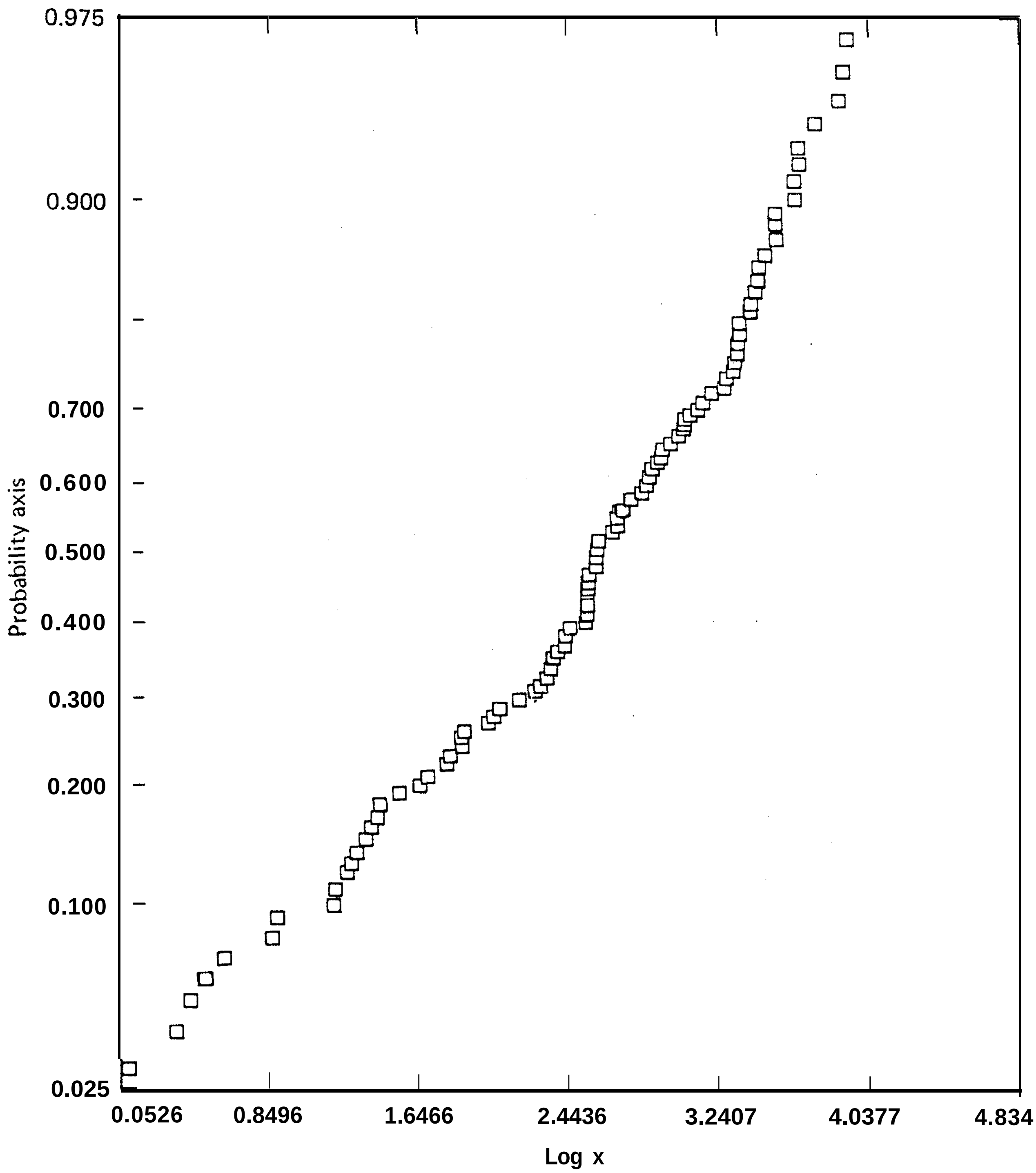

FIG. 10. Concentration of ^{137}Cs in the top 0-15 cm of soil at Enjebi (Janet) Island.

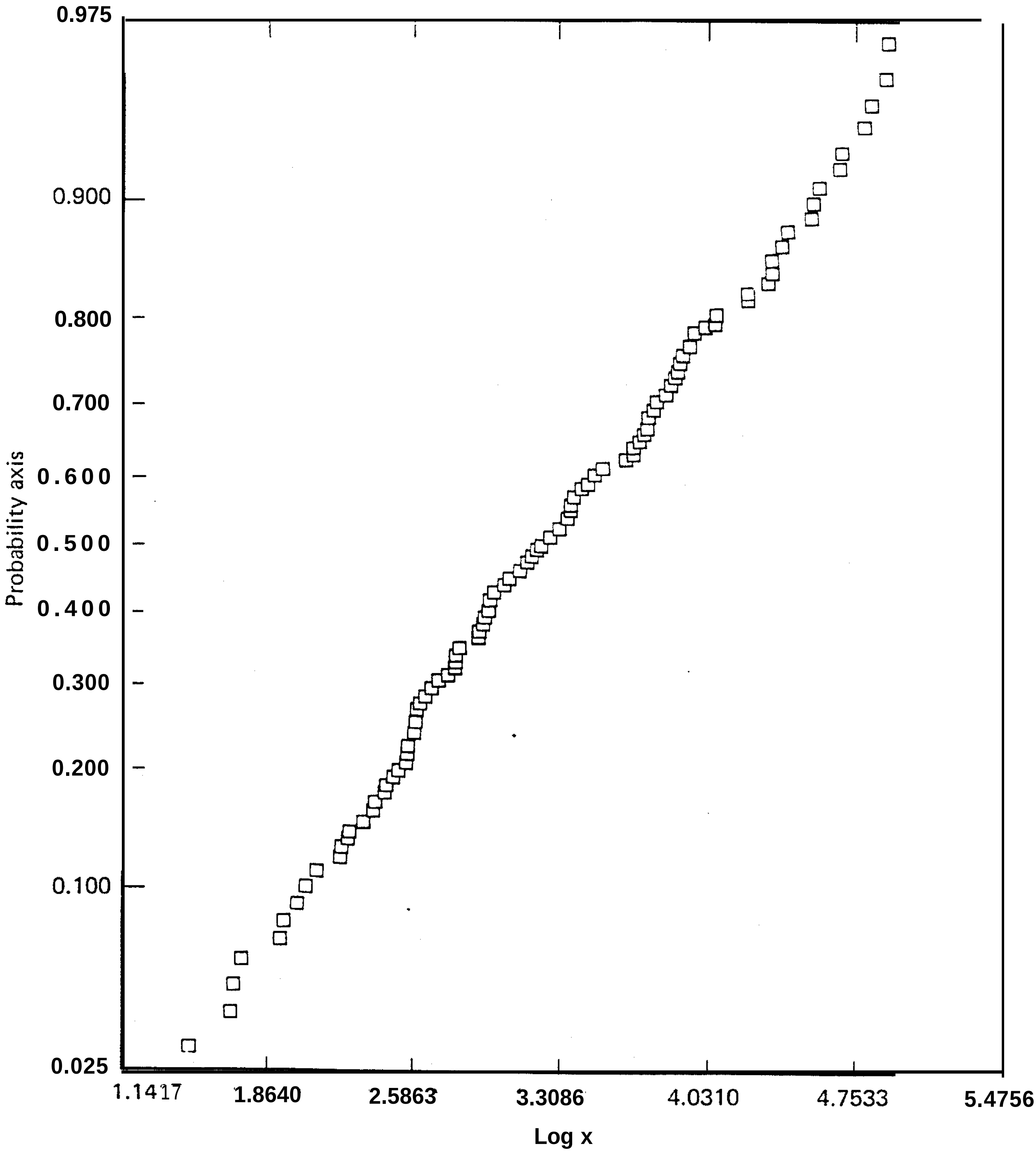

FIG. 11. Concentration of ^{90}Sr in the top 0-5 cm of soil at Enjebi (Janet) Island.

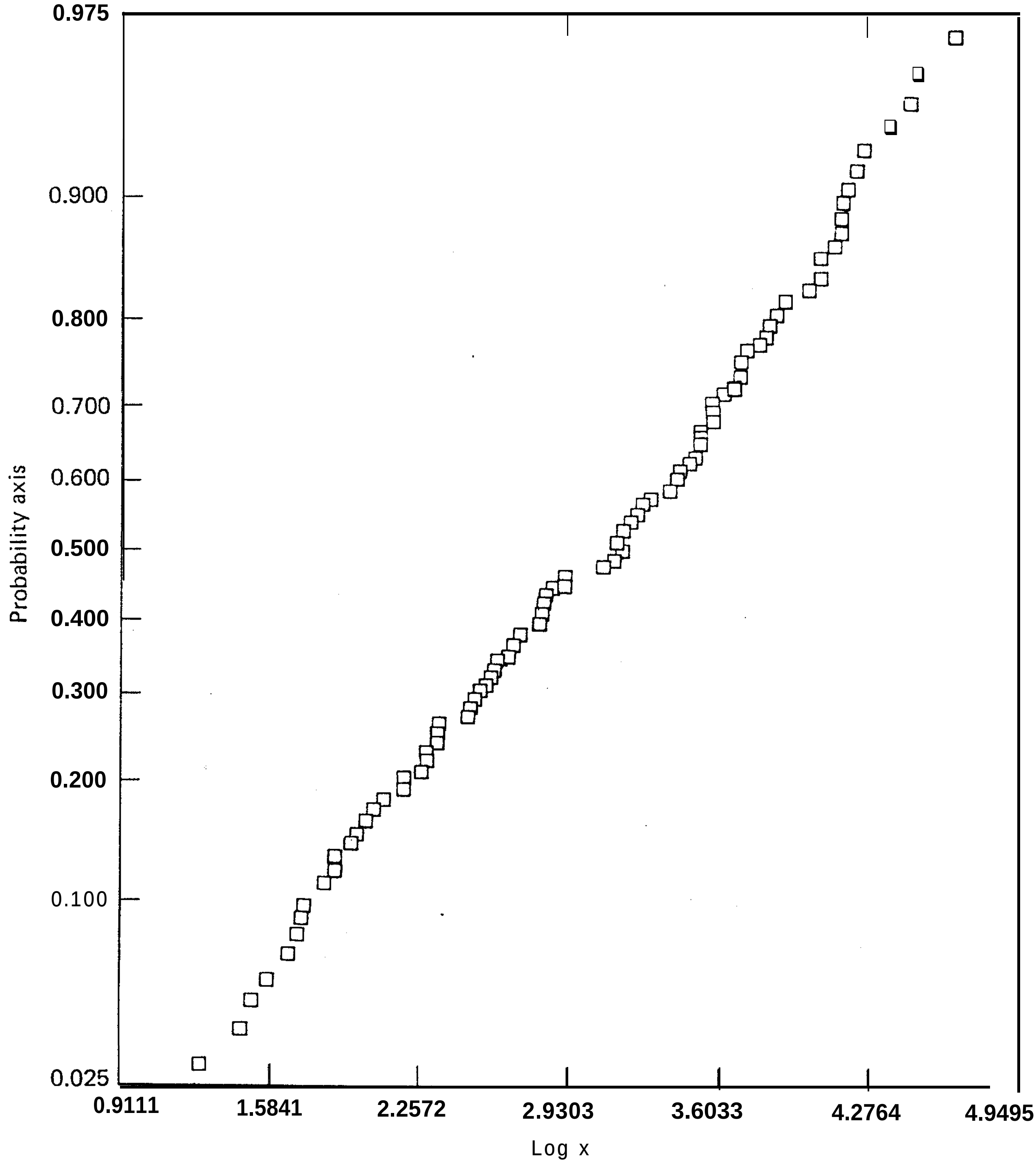

FIG. 12. Concentration of ^{90}Sr in the top 0-15 cm of soil at Enjebi (Janet) Island.

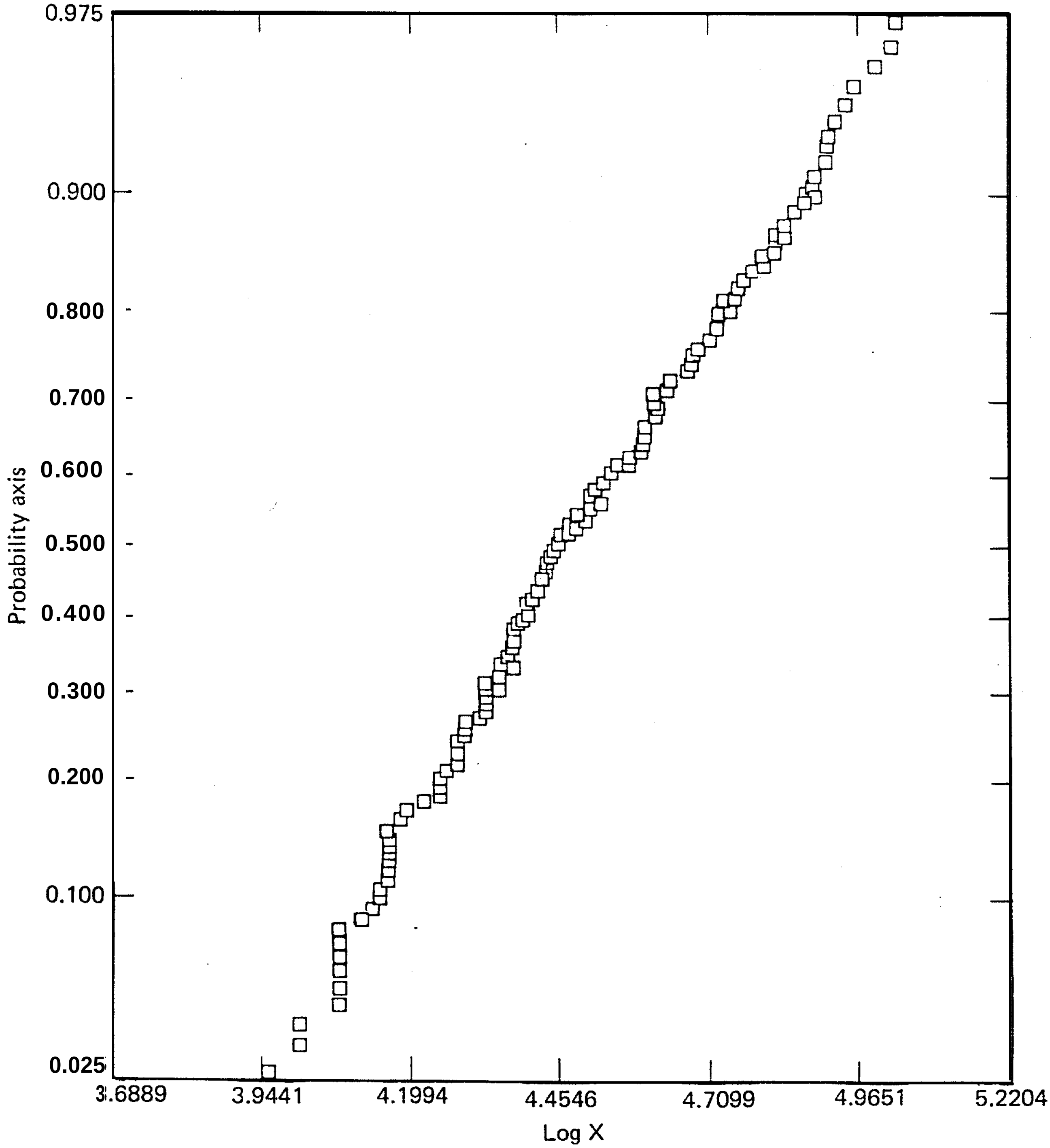

FIG. 13. Log probability plot of the residence time of ^{137}Cs in the body of 152 adult Marshallese males.

the ^{90}Sr component greatly adds to the complexity of the analyses but we are in the process of incorporating the ^{90}Sr model in this type of analysis. However, as mentioned, because the ^{137}Cs accounts for such a large portion of the dose, the analysis of ^{137}Cs will essentially reveal the variation in the final doses and the ^{90}Sr will have a small effect on the distribution.

The method for calculating the distribution in final dose is based on the distribution of each of the parameters and is briefly reviewed here.

The 30-y cumulative dose from the ingestion of ^{137}Cs has been simulated using Monte Carlo techniques. The equation used is:

$$q(t) = q(\phi) \sum_{i=1}^{N} A_i e^{-\alpha_i t} + f_1 f_2' I \sum_{i=1}^{N} A_i \left(1 - e^{-\alpha_i t}\right) / \alpha_i$$

$$Q(t) = q(\phi) \sum_{i=1}^{N} A_i \left(1 - e_i^{-\alpha_i t}\right) / \alpha_i + f_1 f_2' I \sum_{i=1}^{N} \frac{A_i}{\alpha_i} \left[t - \left(1 - e^{-\alpha_i t}\right) / \alpha_i \right]$$

$$R = \frac{51.2 \times E \times q(t)}{M}$$

$$D = \frac{51.2 \times E \times Q(t)}{M}$$

The terms in the equation are:

I	Intake rate (pCi/d); concentration (pCi/g) × dietary intake (g/d)
$q(\phi)$	Initial organ burden (μ Ci) at time $t=t_0$
$q(t)$	Organ burden (μ Ci) at time t
$Q(t)$	Cumulative activity at time t (μ Ci) since t_0
f_1	Fraction of ingested activity from gut to blood
f_2'	Fraction of activity in blood to organ of interest
A_i	Fraction of q(t) in compartment i of organ
B_i	Biological elimination rate for compartment i of organ (d^{-1})
λ	Radioactive decay rate of nuclide (d^{-1})
N	Number of organ compartments
α_i	$\lambda + B_i$ = effective decay rate of compartment i (d^{-1})
M	Organ mass (g)
E	Effective energy of nuclide for organ (MeV)
51.2	Units conversion factor

R Dose rate at time t (rem/d)

D Integrated dose at time t (rem)

The distributions of variables of interest, I (consisting of consumption rate multiplied by concentration), B_i, and M are log-normal (see Figs. 4-13) with geometric standard deviations of 2.0, 1.3, and 1.2, respectively, while A is uniformly distributed. The values for the variables are generated using IMSL (International Mathematics and Statistical Laboratory) routines for log-normal and random (uniform) deviates. Each run generates the appropriate random numbers for each variable for calculating the dose. After storing the dose in the proper histogram bin, the procedure is repeated until 10,000 (or 100,000) trials have been made. The log probability (cumulative distribution) plot for the final doses is shown in Fig. 14.

In addition, the same input data were used with a totally different method[32] for determining the distribution of the final dose, based on the distribution of each of the model parameters. In this approach, the distribution of each input parameter is expressed by a finite probability distribution (FPD), which is a discrete approximation to the continuous probability density function of the parameter. The dose, expressed as an FPD, is estimated by systematically combining the input FPD's in the dose model according to the rules of probabilistic arithmetic and storing the results in the proper previously discretized output bins. This method gives very similar results and the graphic display of

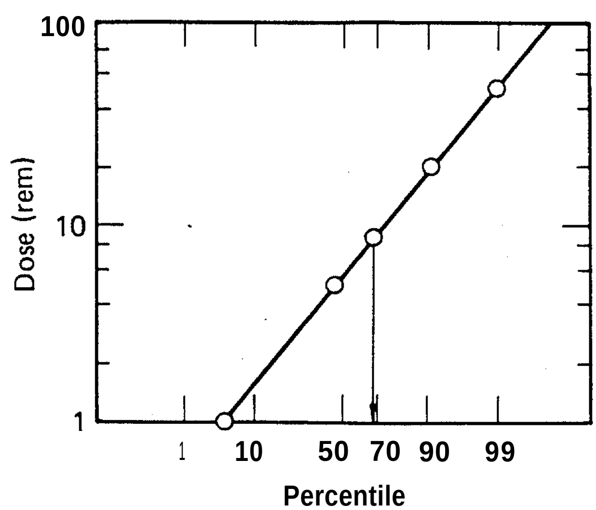

FIG. 14. Log probability plot of 30-y integral dose, with the Monte Carlo method. It is assumed that imported foods are available.

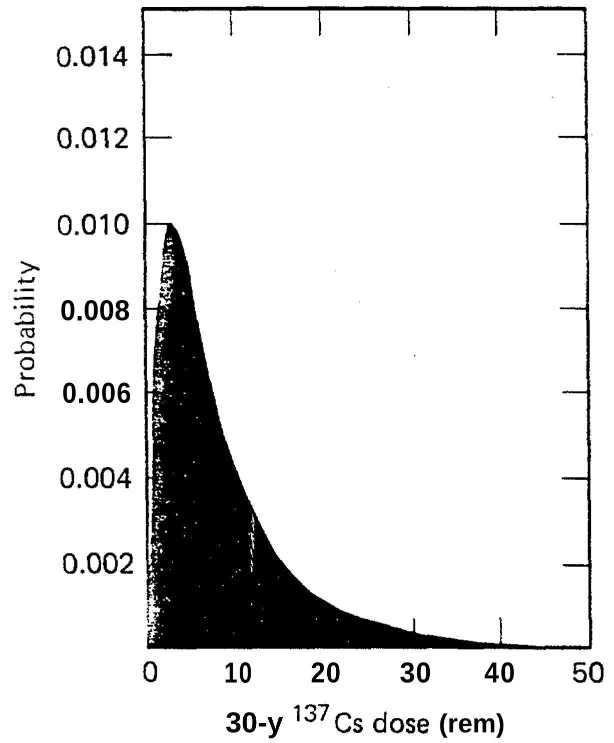

FIG. 15. Linear plot of the 30-y integral doses calculated with the MACRO code.

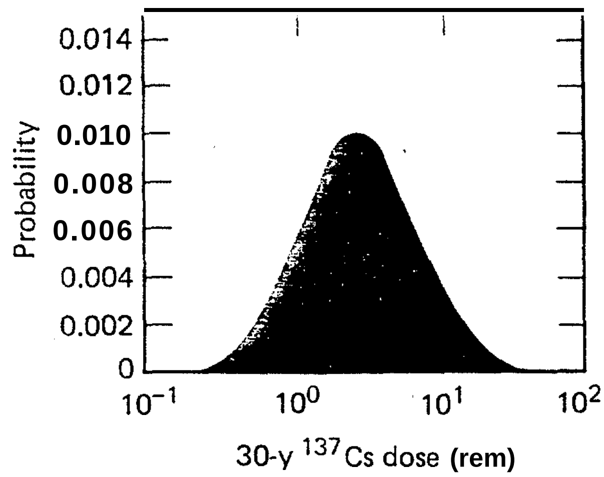

FIG. 16. Log-transformed plot of the 30-y integral doses calculated with the MACRO code.

the final dose distributions from this code for the linear and log-transformed doses are shown in Figs. 15 and 16, respectively.

The "average dose" for Enjebi Island presented in this paper, and calculated using mean values for all of the parameters in the model, falls at the 68th percentile on the distribution for both methods; that is, 68% of the population would be expected to have doses below this value. A dose equal to twice the "average" falls at the 88th percentile for both methods as indicated in Fig. 14; a dose three times the "average" falls at the 95th percentile. Thus 68% of the population would have a 30-y integral dose less than 6 rem, when imported foods are available.

This analysis indicates there is about a 5% chance for a person to receive a dose that is greater than 3 times the average dose. However, there are pragmatic reasons why the probability for such an occurrence is less than that indicated by the analysis. The reasons are that for a person to exceed 3 times the average dose, there would have to be food available at concentrations that exceed 2 or 3 times the average concentration in a quantity that would permit continuous consumption of such high-concentration foods. This is physically impossible, however, because the quantity of available high-concentration foods is not sufficient to provide a continuous diet for a person. There are a few foods in which the radionuclide concentration will exceed 3 times the average concentration but the probability of this occurrence is 5% or less and this does not represent a sufficient quantity of food for continuous consumption of high-activity foods.

CALCULATIONS FOR ALTERNATE DIETARY AND TIME VARIATIONS

There is always an interest in developing dose estimates for living patterns, and options within living patterns, other than those developed in the paper. An enormous number of options could be synthesized and it is of course impossible to include them all in a paper. We have developed those that we feel are most reasonable and most probable. However, we have included in appendices the data necessary to develop the predicted doses for other variations. By proper use of the appendices one can calculate the external gamma, inhalation, and dietary coconut contribution for any period of time, for any island, and for any fraction of the diet that one chooses. These appendices can be obtained from the authors upon request.

Appendix A lists the annual gamma exposure in mrem/y and the cumulative or integral dose in rem for 1 through 70 y for each island. Therefore, once a time distribution on various islands has been established, the external dose can be computed from the data given in Appendix A.

Appendix E lists the doses to the lung and bone due to $^{239+240}Pu$, ^{241}Pu and ^{241}Am as a result of inhalation when 100% of a person's time is spent on the listed island. The doses are based on the inhalation pathway model described in the text. Once again, when a time distribution on various islands has been established, the corresponding lung and bone doses for both dose rates and integral doses can be calculated from the data given in Appendix E.

Appendix F lists the whole-body and bone-marrow annual dose rates and integral doses for normal conditions (where imports are available) and the situation when imports are unavailable that results from the entire coconut intake coming from the listed island after the first 8 y; for the first 8 y, the coconut intake is from the southern islands. The dietary intake of coconut can be prorated among various islands in any fashion desired and the resulting doses can be tabulated; the total dose resulting from any scenario can then be determined. The doses are, of course, based upon the coconut intake listed for the imports-available and imports-unavailable diets in Table 18. Doses for other intakes can be determined by computing a ratio of the intakes and multiplying by the doses listed in Appendix F.

We listed this information just for coconut because it is the only terrestrial food product likely to be consumed from islands other than the residence island. The three islands or complexes evaluated in this report as residence islands—i.e., Enjebi (Janet), Aomon (Sally), Bijire (Tilda)—and the southern islands—Japtan (David), Medren (Elmer), and Enewetak (Fred)—are the only land masses large enough to sustain a significant population. Therefore, the dose tables presented in the text are based on the assumption that the rest of the subsistence crops are derived from the identified residence island.

Appendix D contains the average island radionuclide concentration for soil profiles collected on an island; the results are listed for depths of 0-5 cm, 0-15 cm, and 0-40 cm. These data, in conjunction with the concentration ratios, are the basis for developing the radionuclide concentrations in food products in the terrestrial food chain. In addition, the data can be used to make relative comparisons of islands at the atoll.

DISCUSSION

The doses presented in this assessment are calculated assuming that for northern living patterns the coconut, breadfruit, and Pandanus fruit will come from the southern islands for the first 8 y. At the end of 8 y these local fruits should be available from the first crops planted on the residence island at the time of return.

The diet used to determine the daily intake of radionuclides is the most direct data available on the current dietary habits of the Enewetak people (see Tables 17-24 and Appendix C). The diet is of course very important in predicting doses to a population because the dose will scale directly with dietary intake of locally grown foods. We have mentioned in previous assessments the importance of the diet and the uncertainty that was inherent in previously constructed dietary patterns.[1,8,16] For the first time we have direct input from a significant number (144) of the Enewetak population as a function of age and of dietary conditions. A very interesting report by the Brookhaven National Laboratory on dietary habits at other Northern Marshall Island Atolls will be available soon[14]; it indicates the atoll-specific nature of the dietary intake and supports our concern that specific dietary information is needed for each atoll and each cultural grouping. As an example, if the average coconut intake were assumed to be twice that observed in the Ujelang Diet Survey, then the estimated maximum annual dose rate would be about 60% higher.

The "normal condition" in this report refers to the usual and expected living conditions in which the preferred imported foods are available. For the situation where imported foods are unavailable it is assumed that there is a total dependence on locally grown crops. It is still emphasized that an accurate picture of the diet, especially the consumption rate of locally grown foodstuffs, is extremely important in the dose predictions for resettlement options at the atoll.

The transuranic doses from inhalation and ingestion for ^{241}Am "grow-in" from ^{241}Pu are based on applying the ^{241}Pu/^{241}Am ratio observed on Enjebi (Janet) Island to the entire atoll. The necessary ^{241}Pu data to make these calculations for each island are not yet available. We know the ratio will vary at some of the islands. The results of this increase in ^{241}Am is, however, insignificant in the overall dose picture for some time into the future.

Ingestion doses from ^{60}Co are negligible and therefore do not appear in any of the tables. Usually we cannot detect ^{60}Co in vegetation samples. It is observed at low concentrations in soil samples but incorporation in plants is such that concentrations rarely exceed the detection limit. Cobalt-60 does contribute to the external gamma dose (Appendix A).

Doses from ^{90}Sr, ^{137}Cs and ^{60}Co via the inhalation pathway are 2 to 4 orders of magnitude smaller than doses from the transuranic radionuclides and are therefore not listed in the dose tables.

Uncertainty in the final dose values can result from the uncertainty in three sources of input data: (1) the radionuclide concentration in food (or soil), (2) the dietary intake, and (3) the biological parameters such as radionuclide turnover times in the body, fractional deposition in various organs, and body or organ weight.

The distribution of radionuclide concentration data was discussed in the results and shown in Fig. 8. The distributions are log-normal; the arithmetic mean, $\bar{x}$, includes some 68% of the population; 2 $\bar{x}$ includes 88% of the population, and 3 $\bar{x}$ includes better than 95%. The number of food plants with a concentration 3 times the mean value is less than 5% of the total. Therefore, the probability of a person finding his entire diet for 1, 5, 10, or 30 years from food crops with a concentration of 3 times the mean value is very small. Soil concentration data are also log-normally distributed with similar percentages accounted for by $\bar{x}$, 2 $\bar{x}$, and 3 $\bar{x}$, and reinforce those data observed in coconut meat and fluid; concentrations in plants should, overall, reflect the concentration in soil.

The observed log-normal distribution of radionuclide concentrations in soils and plants at the atolls is consistent with most elemental distributions in nature. Also the observation that 3 times the mean value includes more than 95% of the population distribution is consistent with other observations several of which have recently been summarized by Cuddihy et al.[33]

Strontium-90 concentration distributions in bone have been specifically addressed by Kulp and Schulert.[34] They found that ^{90}Sr from fallout was distributed log-normally and that the 98th percentile value was 2.3 times the mean value. Maximum values observed for ^{90}Sr in bone by Bennett were 3 times the mean; most of the data fell below 3 times the mean.[19-21] These data also reflect the combined variability of the ^{90}Sr concentration in food products and the variability in dietary intake.

The range of values observed for the retention of ^{137}Cs in humans has been summarized in ICRP 10 and 10A[26,27] and NCRP 52.[28] For example, the range of observed values for the retention time for the short-term compartment is 0.5 to 2.1 d with a mean of 1.0 d; the upper limit that has been observed is greater than the mean by only a factor of 2. For the long-term compartment the data range from 60 to 165 with a mean value of 110 d; the maximum value in this case is less than twice the mean value. The fraction of the intake that has been observed to go to the short-term (i.e., 2-d) compartment ranges from 0.02 to 0.22 with a mean of 0.10; for the long-term (i.e., 110-d) compartment the range is 0.78 to 0.97 with a mean value of 0.9. For both cases the maximum value is less than a twice the mean.

The ^{137}Cs gamma-exposure data, which is listed in Table 2, shows that the maximum exposure rate observed at an isolated point on the island is, for most islands, less than 3 times the mean value. In many cases the maximum observed value is only 2 times the mean value. The ^{60}Co data is more variable but it also accounts for a small portion of the external dose over 30 years. Due to the movement of people around their residence island, the variation of individual doses around the average dose is probably minimized and would not add much variability to distribution of doses calculated for the ingestion pathway. In addition, we have not attempted to assess the reduction in external exposure which would occur from spreading crushed coral around the houses and the actual shielding from the houses.

Previous evaluations indicate that dietary intake in a population is log-normally distributed. Our evaluation of the Ujelang Diet Survey confirms the log-normal distribution of dietary intake (Figs. 6 and 7). The distribution of doses is also log-normal and the mean dose calculated using the average value for all model parameters falls at about the 68th percentile; that is, 68% of the population would be expected to have a dose at or below the listed mean value. A dose equal to twice the mean value will include 88% of the population. It is important to recognize when we talk about the average doses in this paper that they are not at the midpoint (or 50% point) of the distribution.

A significant feature of the dose analysis is the tremendous reduction in potential dose to Enjebi (Janet) residents if coconuts from Enjebi (Janet) are removed from the diet and replaced by coconuts from Southern Islands. For this option, maximum annual dose rates for a "maximum individual" are less by nearly a factor of 3 than when coconut come from Enjebi (Janet) Island (Tables 29, 30, and 36). Again, this emphasizes how important the diet is in estimating doses at the atoll and the importance of imported foods in reducing potential doses.

The two scenarios used for estimating the dose to children are for the Enjebi (Janet) Island living pattern because it leads to the highest dose of all the living patterns evaluated. The doses for the case where the child is born at the time the people return are greater than for the case where the child is born 8 y after return. In addition the maximum dose case from birth through 70 y leads to estimated doses which are less than those predicted for adults living on Enjebi (Janet) Island. Thefore, the doses predicted for adults for other living patterns could be used as a conservative estimates for the birth through 70-y dose.

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REFERENCES

1. United States Atomic Energy Commission, Enewetak Radiological Survey, NVO-140, Vol. I, II, and III (1973).
2. W. J. Tipton, A. E. Fritzche, and A. E. Villaire, In Situ Determination of ^{241}Am at Enewetak Atoll, EGG-1183-1781 (to be published).
3. K. Crase, P. H. Gudiksen, and W. L. Robison, External Beta Dose at Enewetak Atoll, Lawrence Livermore Laboratory, Livermore, CA, UCRL-84487 (Preprint, 1980, submitted to Health Physics).
4. J. H. Shinn, D. N. Homan, and W. L. Robison, Resuspension Studies at Bikini Atoll, Lawrence Livermore Laboratory, Livermore, CA, UCID-18538 (1980).
5. Report of the Task Group on Reference Man, ICRP Publication 23, (Pergamon Press, NY, 1975).
6. D. V. Bates, B. R. Fish, T. F. Hatch, T. T. Mercer, and P. E. Morrow, "Deposition and Retention Models for Internal Dosimetry of the Human Respiratory Tract," Health Physics 12, 173 (1966).
7. Limits for Intakes of Radionuclides by Workers, Annals of the ICRP, Publication 30, Part 1, 1979. Pergamon Press, New York, New York.
8. W. L. Robison, W. A. Phillips, and C. S. Colsher, Dose Assessment at Bikini Atoll, Lawrence Livermore Laboratory, Livermore, CA, UCRL-51879, Part 5 (1977).
9. V. E. Noshkin, W. L. Robison, K. M. Wong, and R. J. Eagle, Evaluation of the Radiological Quality of the Water on Bikini and Eneu Islands in 1975: Dose Assessment Based on Initial Sampling, Lawrence Livermore Laboratory, Livermore, CA, UCRL-51879, Part 4 (1977).
10. W. L. Robison and V. E. Noshkin, Plutonium Concentration in Dietary and Inhalation Pathways at Bikini Atoll and New York, Lawrence Livermore Laboratory, Livermore, CA, UCRL-52176 (1976).
11. Final Report: Enewetak Radiological Support Project, U.S. D.O.E. Nevada Operations Office to be published as NVO-213, 1981.
12. Root Activity Patterns of Some Tree Crops, IAEA Tech. Rept. Series No. 170 (Vienna, 1975).
13. C. Domnick, and M. Seelye, "Subsistence Patterns Among Selected Marshallese Villagers," in Laura Report, L. Mason, Ed. (University of Hawaii, Honolulu, Hawaii, 1967), pp. 1-41.
14. J. Naidu, N. A. Greenhouse, G. Knight and E. C. Craighead, Marshall Islands: A Study of Diet and Living Patterns, Brookhaven National Laboratory, Upton, NY, BNL-51313 (1981).

15. Observations of Lawrence Livermore Laboratory field team members during several trips to the Atoll.

16. M. Muri, Nutrition Study in Micronesia, Atoll Research Bulletin, 27 (1954).

17. N. Greenhouse and R. Miltenberger, Brookhaven National Laboratory, Upton, NY, private communication (1979); to be published.

18. R. A. Conrad, Ed., A Twenty Year Review of Medical Findings in a Marshallese Population Accidentally Exposed to Radioactive Fallout, Brookhaven National Laboratory, Upton, NY, BNL-50424 (1975).

19. B. C. Bennett, Strontium-90 in Human Bone. 1972 Results from New York City and San Francisco, Health and Safety Laboratory, USAEC, NY, HASL-274 (1973).

20. B. C. Bennett, Strontium-90 in Human Bone. 1976 Results from N. Y. and San Francisco, Health and Safety Laboratory, USDOE, NY, HASL-328 (1977).

21. B. C. Bennett and C. S. Klusek, Strontium-90 in Human Bone 1977 Results from New York City and San Francisco, Environmental Measurement Laboratory (EML), USDOE, N.Y., EML-344 (1978).

22. F.W. Spiers, Radioisotopes in the Human Body: Physical and Biological Aspects (Academic Press, New York, 1968).

23. B. G. Bennett and J. Harley, EML, USDOE, NY, personal communication.

24. A Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly, Ionizing Radiation: Levels and Effects (United Nations, New York, 1972).

25. A Review of Radiosensitivity of the Tissues in Bone, ICRP Publication 11 (Pergamon Press, NY, 1968).

26. Recommendations of the International Commission on Radiological Protection. A Report of Committee 4 on Evaluation of Radiation Doses to Body Tissues from Internal Contamination due to Occupational Exposure. ICRP Publication 10 (Pergamon Press, London, 1968).

27. Recommendations of the International Commission on Radiological Protection. Report of Committee 4 on Assessment of Internal Contamination Resulting from Recurrent or Prolonged Uptakes. ICRP Publication 10A (Pergamon Press, London, 1971).

28. Cesium-137 From the Environment to Man: Metabolism and Dose, NCRP Report No. 52 National Council on Radiation Protection and Measurements, Washington, DC, NCRP-52 (1977).

29. G.G. Killough and P.S. Rohwer, INDOS-Conversational Computer Codes to Implement ICRP-10-10A Models for Estimation of Internal Radiation Dose to Man, Oak Ridge National Laboratory, Oak Ridge, TN, ORNL-4916 (1974).

30. R. Mitlenberger and N. Greenhouse, Brookhaven National Laboratory, Upton, NY, private communication (1979).

31. The Metabolism of Compounds of Plutonium and Other Actinides, A report of the Task Group of Committee 2, ICRP Publication 19 (Pergamon Press, NY, 1972).

32. L. L. Edwards MACRO 1: Code to Test a Methodology for Analyzing Nuclear-Waste Management Systems, Lawrence Livermore Laboratory, Livermore, CA, UCRL-52736 (1979).

33. R. G. Cuddihy, R. O. McClellan, and W. C. Griffith, "Variability of Organ Doses in Individuals Exposed to Toxic Substances," Toxicol. Appl. Pharmacol. 49 (1979).

34. J. L. Kulp and A. R. Schulert, "Strontium-90 in Man V," Science 136, 619-632 (1962).

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